ANIMAL NUTRITION

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ANIMAL NUTRITION

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PREFACE.

In a former volume—*The Chemistry of Crop Production*—I have endeavoured to set out in the form of a connected story the scientific principles of the cultivation of the soil. This volume deals with the second main adventure of the farmer, namely the utilisation of the produce of the soil for the feeding of animals. Its aim is rather to tell a connected and intelligible story than to give exhaustive information about every detail of the feeding of animals. Readers who are interested in the story can readily fill in the detail from other sources quoted in the text.

In the chapters dealing with the computation of rations, I have adopted a somewhat novel point of view, substituting for the system of standard rations, which has persisted with a minimum of change since Wolff's first publication in 1864, a much more elastic system of computing rations according to the result which the feeder desires to produce. I am convinced that this system already used in computing rations for milch cows has come to stay. It appeals more to the intelligence than to the memory, and is consequently more interesting, easier both for the teacher and the student, and more useful to the practical man.

I have much pleasure in acknowledging valuable help and suggestions received from my colleagues Messrs. J. W. Capstick, E. T. Halnan, and H. E. Woodman, who have been good enough to read parts of the MS. and proofs.

T. B. WOOD.

School of Agriculture,
Cambridge.
January 1924.

NOTE TO THE SECOND EDITION.

The most important alterations introduced in this reprint are:—

1. A revision of the fundamental data for rationing pigs, made possible by recent work at Cambridge.
2. Revision of the figure for digestible protein in roots. The figure now given is "protein equivalent," *i.e.*, pure protein plus half the difference between pure and crude protein.
3. The figures for starch equivalent content of hays and straws have been raised by one-fifth in accordance with Armsby's determinations of the net energy of coarse fodders.

T. B. W.

March 1927.

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CHAPTER I.

PLANT AND ANIMAL METABOLISM.

Scope.

The word agriculture originally meant the cultivation of the soil for the production of crops. This, however, is to-day only one branch of agricultural practice, for every farmer is concerned not only with growing crops, but with their utilisation for the feeding of animals. In a former volume, *The Chemistry of Crop Production,* we have endeavoured to set out the general scientific principles which underlie the successful practice of arable cultivation. This volume is intended to expound on similar lines the general scientific principles which underlie the successful feeding of animals.

How Plants Feed.

Anyone who has read the former volume, or any similar book on soils and manures, will be aware that plants obtain the constituents of their food from the air and from the soil in the form of very simple compounds which are not capable of giving out heat or energy, or even of actively combining with one another to form the substance of the plant.

Plants, however, do not appear at first sight to require energy on the same scale as animals, for their power of movement is almost negligible, and they are not noticeably warmer than their surroundings. They do nevertheless require energy for the building up of their own substance and for growth, and this energy they absorb from sunlight by the agency of their green colouring matter—chlorophyll.

Plant Metabolism.

Briefly, plants take in carbon dioxide from the air, and water and simple salts from the soil. By means of the energy of sunlight which is absorbed by their chlorophyll they build up these simple substances into the complex materials of which their structure is composed. A small proportion of these complex materials is decomposed to yield the comparatively small amount of energy required for growth and the various other functions of the plant. The greater part, however, is stored for the future use of the plant or of its progeny, sometimes in seeds, sometimes in stems or roots, and it is this power of storing reserve materials which makes plants valuable as food for men and animals. Thus the result of all the chemical changes occurring in plants, which are collectively called the plant's metabolism, is the building up of much complex material, most of which is stored for future use.

Animal Metabolism.

A few simple experiments on ourselves will show that animal metabolism proceeds on very different lines. Insert a clinical thermometer into the mouth so that the bulb is under the tongue. Close the mouth and keep the thermometer in position for at least a minute. Withdraw the thermometer and read the temperature. It will be found to be 98·4° F. or thereabouts, whatever the temperature of the air may be. Similar experiments may be made with horses, cattle, sheep, and pigs. In finding the body temperature of such animals it is usual to insert the thermometer in the rectum instead of in the mouth. The average body temperatures of farm animals are as follows:—

Horses	100·4° F. to 100·8° F.	Sheep	103·6° F. to 104.4° F.
Cattle	101·8° F. to 102·0° F.	Pigs	101° F. to 105° F.

These are temperatures very seldom reached by the air of Great Britain, and we may conclude that animals must possess some kind of internal arrangement for keeping their bodies warm or maintaining their body temperatures.

To maintain the body at a higher temperature than that of the surrounding air heat must be provided.

Source of Animal Heat.

This heat does not come from the sunlight, for the body temperature is the same in summer and winter and in light and darkness. Where then does it come from? Make a small heap of dry hay on an iron plate or dish and set fire to it. Note that the hay burns giving out heat and that its products of combustion are carbon dioxide and water vapour.

Hay is one of the commonest foods consumed by farm animals. It can burn and give out heat in the process and at the same time it forms carbon dioxide and water vapour. Possibly it does this in the animal's body. If so, then the animal must get rid of the carbon dioxide and water vapour. Breathe into a cold glass vessel and note that the glass becomes steamy, showing that your breath contains water vapour. Note also the steaminess of the breath of animals in cold weather. This is due to the condensation of the water vapour in their breath when it meets the cold air.

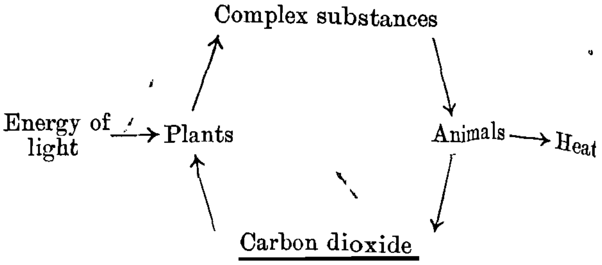
Now breathe through a glass tube into some clear lime-water, and note that your breath turns the lime-water milky. Your breath therefore must contain carbon dioxide. This experiment is not easy to repeat with a large animal. It has, however, been done many times, and has shown that animals like ourselves expire carbon dioxide. We can now put two and two together. Hay will burn to form carbon dioxide and water vapour. When it burns heat is given out. Animals eat foods such as hay and expire carbon dioxide and water vapour. Evidently these products arise from the oxidation of the hay inside the body. This oxidation produces heat, and this heat is utilised for maintaining the body temperature.

Take a number of other substances which are used for feeding animals, for instance bran, crushed oats, straw, linseed cake. Place small quantities of each in a metal spoon, heat in a flame and note that they all burn with varying readiness, and that on burning they all give out heat and

form carbon dioxide and water vapour. What is true of hay is true of other feeding stuffs, and we can now make the general statement that animals feed on the complicated combustible materials made by plants, which are oxidised in their bodies with the formation of carbon dioxide and water vapour, and with the production of heat which is used to keep their bodies warm.

Plants and Animals Compared.

We can now contrast the metabolism of plants and animals, metabolism being the word used by physiologists to express the sum of the chemical changes which go on inside a living thing. Plants take in from the air and the soil carbon dioxide, water, and simple salts. By means of the energy which their green colouring matter absorbs from sunlight they build up these simple substances into the complex materials of which their structure is composed. Animals eat these complex materials breaking them down into carbon dioxide, water, and other simple substances and using for their own purposes the energy which was absorbed from the sunlight by the plants in their making. The carbon dioxide, water, and simple substances excreted by animals are again absorbed by plants. Thus plants are necessary for the feeding of animals and animals play their part in feeding plants. The annexed diagram illustrates graphically the interdependence of plants and animals.



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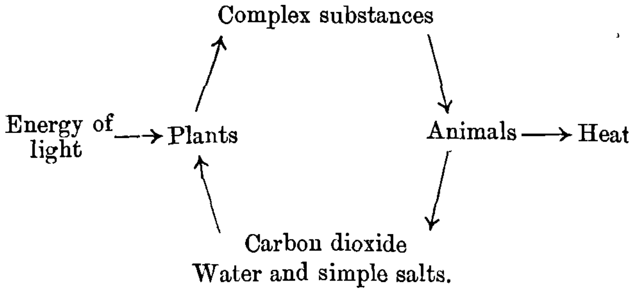

DIAGRAM I.

PLANT AND ANIMAL METABOLISM.

In *Chemistry of Crop Production* we studied the relations between plants and the air and soil and learned how to help crops to get all the simple substances they need for their nutrition. Our present task is to study the fate of these simple substances in the plant, how they are built up into complex substances and stored in certain organs and how they are used for feeding animals.

CHAPTER II.

THE CONSTITUENTS OF PLANTS.

We have seen that animals depend for their subsistance on the stores of complex materials built up by plants with the aid of the energy of sunlight from simple substances absorbed from the air and from the soil.

Formation of Starch by Plants.

The details of this building-up process are not yet fully understood, we know, however, that the beginning and end of one of the most important of these processes can be expressed by the following equation :—

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{5H_2O} = \underset{\text{Starch}}{C_6H_{10}O_5} + \underset{\text{Oxygen.}}{6O_2}.$$

This process is known as photosynthesis or assimilation. It goes on only in green plants exposed to light. The plants absorb CO_2 from the air by their leaves. The H_2O is absorbed from the soil by the roots. The products are $C_6H_{10}O_5$, starch, which is stored in the plant, and oxygen which is returned to the air.

We cannot directly convert CO_2 and H_2O into starch and oxygen by experimental methods in the laboratory. The plant makes this conversion by means of the energy of light which is absorbed by the chlorophyll and handed on to the plant's' protoplasm or living substance.

Heat of Combustion.

It is difficult, too, to measure how much energy a plant absorbs in order to make a given weight of starch. We can, however, burn a given weight of starch in oxygen, and measure the amount of heat given out, and this must be the equivalent of the energy absorbed. If it were not, then by first building up

starch from CO_2 and H_2O and then burning it in oxygen, it would be possible to increase or decrease the energy in a given weight of the four substances CO_2, H_2O, starch, and oxygen. This would be breaking the law of the conservation of energy, one of the great natural laws, which states that whilst the total energy in any given weight of substances can be changed from heat into work or electricity or light or any other form of energy, its amount cannot be increased or diminished.

To measure the heat given out by burning a given weight of starch in oxygen we proceed as follows: a small quantity of pure starch accurately weighed is placed in a platinum vessel inside a steel bomb. The bomb is then filled with oxygen under pressure and placed under the water in a vessel which is insulated to prevent loss or gain of heat. After standing for some time the temperature of the water is taken very accurately. The starch is then lighted by electrical means when it burns completely in the oxygen. The heat given out by the burning warms the bomb, the water which surrounds it, and the insulated vessel.

Let us suppose that the weight of starch burned is 1 gm., the rise in temperature 1·767° C., the weight of water in the insulated vessel 2,000 gm., and that the bomb and the insulated vessel together require as much heat to warm them as would 320 gm. of water.

The calculation will then be made as follows, one calorie or unit of heat being the amount of heat required to warm 1 gm. of water through one degree Centigrade. Adding together the water in the calorimeter, 2,000 gm., and the water equivalent of the apparatus, 320 gm. the total weight of water warmed is 2,320 gm. The temperature through which it was warmed is 1·767° C. The quantity of heat required was therefore $2{,}320 \times 1{\cdot}767 = 4100$ calories, and this was given out by burning 1 gm. of starch.

1 lb. of starch can give out $4{,}100 \times 454$, or 1,861,400 calories. This is a very large figure, so large as to be inconvenient. To meet this difficulty we usually adopt a

larger unit of heat, namely the large or kilocalorie, which is equal to 1,000 ordinary calories. In terms of this unit, the amount of heat which 1 lb. of starch can give out is 1,861 kilocalories.

Starch in Crops.

Starch is one of the most abundant constituents of plants Wheat, for instance, contains about 60 per cent. of starch in the grain alone. An average wheat crop yields per acre 32 bushels of grain, and, since a bushel of wheat normally weighs 63 lb., the grain of an average acre of wheat weighs $63 \times 32 = 2016$ lb. This will contain $2016 \times \frac{60}{100} = 1210$ lb. starch. Taking the heat of combustion (which is the name given to the quantity of heat given out by burning 1 lb. of a substance) of starch as 1,861 kilocalories, the total amount of starch in the grain of an average acre of wheat is capable of giving out 1210×1861 kilocalories $= 2{,}251{,}810$ kilocalories.

Again, this figure is inconveniently large, so once more we choose a larger unit, a thousand times as large as the kilocalorie. This we call a therm, and in terms of this new unit, the starch in an acre of average wheat can give out 2,252 therms.

The green colouring matter must have absorbed at least an equivalent amount of energy from the sunlight.

An average steer requires about 7 therms per day to maintain his body temperature and to provide the energy for carrying out his vital functions. The starch in an acre of average wheat can, therefore, provide the necessary heat and energy for an average steer for 322 days, or $10\frac{3}{4}$ months; and all this heat and energy comes originally from sunlight, which enabled the leaves of the wheat to build up 1,210 lb. of starch containing energy which can produce 2,252 therms of heat.

Other Plant Constituents.

Starch is only one of the complex substances built up by the plant. Others are various kinds of sugars which are contained in nearly all plant juices, and especially in the juice of the sugar cane and of the sugar beet: gums which are also common in plant

juices but are perhaps best known in the case of the gummy material which oozes out of wounds in the bark of cherry and plum trees: cellulose and woody fibre which form the harder parts of plants corresponding to the skeleton of animals. All these substances, starch, sugars, gums, cellulose and woody fibre are direct or indirect products of photosynthesis.

Carbohydrates.

They resemble each other in being composed of carbon in combination with hydrogen and oxygen, the latter two elements being present in the same proportion as that in which they are combined in water. For this reason these substances are all included in the great class of compounds called carbohydrates, which means compounds of carbon and water.

Oils.

These, however, are by no means all the complex substances found in plants. Everyone has heard of linseed oil which is used for making paint, of colza oil which before the days of paraffin was commonly burned in lamps, of palm kernel oil from which margarine is made. These oils are obtained from linseed, from rape or cole seed, and from palm kernels, because these particular plants happen to contain oils in great abundance in their seeds. All plants are by no means so rich in oils as these, but oils are nevertheless found in smaller quantities in nearly all plants. And very important constituents they are from the point of view of the feeding of animals, for 1 gm. of oil when completely burned in oxygen gives out 9,400 calories or more than twice as much heat as a similar weight of starch.

Oils are like carbohydrates in that they are compounds of carbon, hydrogen, and oxygen, but their chemical structure is quite different. They are not formed in plants by direct photosynthesis. Indirectly this process must be responsible for their origin, but the exact steps in their formation are not known. Probably starch is formed first and changed into oils during the course of the plant's metabolism.

The building up process in plants does not stop at carbohydrates and oils. We know that plants take in from the soil compounds of nitrogen, phosphates, and other salts. These are built up together with carbon, hydrogen, and oxygen into still more complex substances known as proteins. The best known plant protein is the gluten of wheat, which is easily obtained by the following method. Place a small quantity of ordinary wheat flour on a square of fine muslin, gather the edges of the muslin together and tie them with a piece of string. Moisten with tepid water and rub under a jet of water until the water no longer runs away milky. Now open the muslin and take out the elastic sticky substance which remains inside. This is gluten. By suitable tests it can be shown to contain carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. It is one example of the class of exceedingly complex substances known as proteins which are found in varying proportions in all plants. These three great classes of complex substances, the carbohydrates, the oils, and the proteins, are by far the most abundant constituents of plants. Plants contain, however, many other substances in smaller quantities, among which may be mentioned the amides, which are steps in the building up of the proteins, acids which are probably steps in the oxidation of the carbohydrates, and a great variety of substances which give plants their characteristic scents and flavours. In addition to these organic compounds which are converted into gaseous products when the plant is burned, plants contain a certain proportion of inorganic materials, such as lime, potash, and phosphates, which when the plant is burned are left behind in the form of ash.

Proteins.

Other Constituents.

Ash.

To summarise, plants consist of carbohydrates, oils, proteins, amides, acids, scents and flavours, and ash. In due course we shall find out which of these substances are important to animals.

CHAPTER III.

STARCH AND SUGAR.

Before proceeding further it is necessary to learn something more about the classes of complex substances of which plants are composed, and we will begin with the carbohydrates because they are so far as we know the first things formed in the plants by the process of photosynthesis.

Preparation of Starch.

Let us repeat the experiment by which we obtained wheat gluten, but in rather a different way. Tie up a small quantity of wheat flour in a piece of muslin as before. Moisten it with tepid water, and rub it between the thumb and fingers in a large vessel of water. The water will become milky, and on standing for a short time a fine white powder will settle at the bottom. This powder is starch. Pour off most of the water and examine the powder.

Microscopic Examination.

Transfer a very little of it to a glass slide, cover it with a cover slip and look at it under a microscope. It will be found to consist of very small more or less rounded grains. Starch consists of small separate grains. The starch grains of different plants have characteristic sizes and shapes by means of which they can be identified. Thus it is possible by examining starch grains under the microscope to decide whether they come from wheat, barley, oats, maize, peas, or potatoes.

Tests for Starch.

Put a small quantity of the starch into a test tube, add some cold water and shake. Note that it does not dissolve. Starch is insoluble in cold water. Now heat the test tube. Note that before the water boils, the starch swells up, and dissolves in hot water, making, however, a rather opalescent solution. Cool the test

tube by holding it under the tap. If you have used enough starch the solution will become thick, and set to a kind of jelly. Starch dissolves in hot water, the solution is opalescent, and if strong sets on cooling.

To a little of the cold solution add a few drops of iodine solution. Note that a blue colour is formed. Warm the test tube; the blue colour disappears, but returns on cooling. Starch is evidently quite an easy substance to identify. Starch grains have definite and characteristic shapes and sizes. Starch is insoluble in cold water. It dissolves in hot water. The solution becomes thick on cooling. The cold solution gives a deep blue colour on addition of iodine. This blue colour disappears on warming but returns on cooling.

Test for starch in various plants by making use of these properties as follows:—

Testing Plants for Starch. Boil a small quantity of the plant in water. Pour off the liquid. Cool it and add iodine. A blue colour, which disappears on heating but returns on cooling, shows the presence of starch.

By applying these tests to different plants and plant products it will be found that starch is a common constituent of almost all plants. It is always found in the plant in the form of starch grains. Although the grains of each plant have characteristic shapes and sizes, the starch of which all starch grains are composed is chemically the same.

Sugars. Everyone knows that certain plants, for instance the sugar beet and the sugar cane, contain sugar, but it is not so well known that there are many different kinds of sugar. This is nevertheless the case, and at least five kinds of sugar are of importance to the agriculturist. These are: cane sugar which occurs not only in the sugar cane and sugar beet but in mangolds, turnips, parsnips, and many other plants: grape sugar which occurs in grapes, turnips and many other plants: fruit sugar which is a common constituent of fruits, flowers, and honey: malt sugar which is found in germinated seeds: and milk sugar which as its name

implies occurs in milk. In many books on the feeding of animals these sugars are frequently called by their chemical names and it is therefore desirable that these names should be mentioned here. They are as follows:—

Cane sugar	Sucrose or saccharose
Grape sugar	*d* Glucose or dextrose
Fruit sugar	*d* Fructose or laevulose
Malt sugar	Maltose
Milk sugar	Lactose

It is by no means an easy matter to identify each of these sugars, and for our purpose it is not necessary that we should be able to do so, for they are all practically equal in food value. They are not, however, equal in sweetness, cane sugar being far sweeter than any of the other kinds. For our purpose it will suffice if we can find a general test for the presence of sugar of any kind.

Make solutions of all the different sugars mentioned above.

Tests for Sugar.

Test each solution as follows:—To a little of the solution add a little Fehling's solution and boil. In the case of all the sugars except cane sugar, the blue colour of the Fehling's solution will disappear and a red precipitate will be formed. This seems to be a general test for all the common sugars except cane sugar.

Take a second portion of cane sugar solution, add to it a little dilute sulphuric acid, and boil for a moment. Neutralise the acid by adding a little sodium hydrate solution, then add Fehling's solution and boil. The blue colour will disappear and a red precipitate will separate as with the other sugars.

By means of this test we can find if a plant or a part of a plant contains any kind of sugar. The procedure is as follows:—Since all sugars are soluble in water, sugar is likely to be found in the plant's juice, or, if the plant is dry, in the extract obtained by shaking the ground up material with cold water. The best way of preparing plant juice in the case of the turnip, mangold, potato, or other "root" is to cut the root

Testing Plants for Sugar.

into strips and put them through a sausage mill. Then tie up the pulp in a piece of fine linen and squeeze out the juice. Plant juice or extract is usually too thick and dark coloured to be suitable for testing without further treatment. The best way to make it clear is to add to it about one-tenth of its volume of basic lead acetate solution. This causes a bulky white precipitate which carries with it all the substances which make it thick and muddy and most of the colour. On filtering off this precipitate a clear liquid runs through which is suitable to test for sugar as described above. By testing a number of plants in this way it will be found that sugar, of one kind or other, is a common constituent of almost all plants, and that it is specially abundant in roots such as turnips, mangolds, and parsnips and carrots.

Conversion of Starch into Sugar by Acids.

Starch and the sugars both belong to the great class of substances known as carbohydrates, and they are rather closely related to each other as is shown by the fact that starch can readily be transformed into sugar. Put a little starch into a small flask with some water. Add a little dilute sulphuric acid and boil for at least five minutes. At intervals pour out a little of the solution into a test tube, cool it, and add a few drops of iodine solution. Note that as the boiling proceeds, the solution loses the power of giving a blue colour with iodine, showing that the starch is undergoing change. When the solution no longer gives any colour with iodine, transfer a portion to a test-tube, neutralise it with sodium hydrate solution, add a little Fehling's solution and boil. The blue colour of the Fehling's solution is destroyed and a red precipitate appears, showing that sugar has been formed. Starch is therefore changed into sugar by boiling with acid.

Conversion by Enzymes.

Prepare some starch solution by boiling a very little starch with water in a test-tube. Fix the test-tube in a vessel of water warmed to 50° C., and kept at that temperature by means of a very small flame.

Meantime, shake up a little finely ground malt with some cold water and pour it on to a filter. Malt is barley which has been made to germinate and then dried so as to kill the root and shoot and thus prevent further growth. The liquid which runs through the filter is malt extract. Add a little of the malt extract to the warm starch solution in the test-tube. By means of a glass rod, place a number of drops of iodine solution on a porcelain slab or failing this on a piece of glazed paper. Dip another glass rod into the warm starch solution to which the malt extract has been added, and transfer a drop of the solution to one of the drops of iodine. A blue colour will appear because the starch will combine with the iodine. Repeat this experiment every minute or so. Less and less blue colour will be formed, and finally after a few minutes, no colour at all. Something in the malt extract has changed the starch.

Now pour some of the starch solution which has been changed into a test-tube, and add a little Fehling's solution. Before boiling it put an equal volume of water into a second test-tube and add to it about the same proportion of malt extract as you added to the starch solution, and then a little Fehling's solution. Boil the two test-tubes side by side. In that containing the changed starch solution much red precipitate will be formed, in that containing only water and malt extract only a trace. This trace represents the sugar contained in the malt extract. Of the larger quantity formed in the test-tube containing the changed starch solution, a trace also came from the sugar in the malt extract, but the greater part from sugar formed from the changing of the starch. Evidently malt or germinated barley contains something which can change starch into sugar.

Enzymes.

Repeat the experiment, but boil the malt extract before adding it to the starch solution. Note that boiled malt extract has lost the power of changing starch. The constituent of malt extract which changes starch into sugar is destroyed by boiling. It

is a ferment or enzyme called diastase, and its function in the germinating seed is to convert the store of insoluble starch in the seed into sugar, so that the juice or cell sap may dissolve the sugar so formed, and carry it to the root and shoot where it is required to provide material for growth.

Such ferments or enzymes are common in plants, their funtion being to change the starch formed by photosynthesis or that stored in roots or tubers into sugar whenever the plant wants to move it from leaves to roots, from roots to stems, or elsewhere.

Formulae of Starch and Sugar.

The ease with which starch may be converted into sugar is well illustrated by the similarity of their chemical formulae. Chemical experiments have shown that in starch the elements carbon, hydrogen, and oxygen are combined in the proportion of six atoms of carbon, ten atoms of hydrogen, and five atoms of oxygen. The simplest formula for starch would therefore be $C_6H_{10}O_5$. Experiments have shown, however, that the real formula is more complicated. We are not sure what it is, but we know that it is probably not less complex than $C_{60}H_{100}O_{50}$.

It has been shown that the formula of grape sugar and fruit sugar is $C_6H_{12}O_6$, and of cane sugar, malt sugar, and milk sugar $C_{12}H_{22}O_{11}$. The similarity of these formulae is obvious. Thus, if we add to starch, $C_{60}H_{100}O_{50}$, ten times H_2O we get ten times $C_6H_{12}O_6$—thus:—

$$C_{60}H_{100}O_{50} + 10\,H_2O = 10\,C_6H_{12}O_6.$$

Something of this kind occurs when starch is converted into sugar by boiling with acid, the acid changing the starch by making it combine with water.

Similarly the action of acid on cane sugar is represented by the equation—

$$C_{12}H_{22}O_{11} + H_2O = 2\,C_6H_{12}O_6.$$

Another point of similarity between starch and the sugars is that in all of them the hydrogen and oxygen are present

in the same proportion as in water H_2O. Thus the formulae can be written $C_{60}50(H_2O)$, $C_{12}11(H_2O)$, $C_6 6(H_2O)$, in which they all appear as compounds of carbon with water. Since compounds of substances with water are called hydrates, we might call starch and the sugars carbon hydrates. As a matter of fact chemists have contracted these two words into one—carbohydrates.

CHAPTER IV.

CELLULOSE AND SOME LESS IMPORTANT CARBOHYDRATES.

The great group of substances called carbohydrates includes many other members besides starch and the sugars which we have just considered.

Cellulose.

The most important of these is the substance called cellulose, which forms the cell walls and other supporting parts of plants.

As might be expected, from the part it plays in the plant economy, this cellulose is more insoluble and less prone to change than the other plant constituents. It is by taking advantage of this fact that we are able to separate and identify cellulose.

Preparation of Cellulose.

Take a small quantity of finely ground or chopped plant substance. Ground oats or finely chopped straw are suitable for this experiment. Pour into a beaker 200 c.c. of water. Put a label on the beaker to mark the level at which the water stands. Pour away the water, and put the ground oats or chopped straw into the beaker. Now pour into the beaker 25 c.c. of dilute sulphuric acid, and fill up to the 200 c.c. mark with water. Cover the beaker with a clock glass, and boil over a small flame for half-an-hour. Care must be exercised when boiling first begins to prevent frothing. Afterwards, when the size of the flame is properly adjusted, boiling will proceed without further attention.

After half-an-hour's boiling, filter through a piece of fine linen tied over a funnel, and wash the insoluble material well with hot water. Pour some of the filtrate into a test-tube, neutralise with sodium hydrate solution, add Fehling's solution, and boil. Note that sugar is present. The boiling with acid has dissolved all the starch and sugar in the material under experiment.

Remove the linen from the funnel and stretch it over a clock glass. With a spatula or blunt knife scrape the insoluble material off the linen, and put it back in the same beaker, washing back the last traces with a jet of water from a wash-bottle. Add to it 25 c.c. of sodium hydrate solution, and fill up to the 200 c.c. mark with water. Cover with a clock glass and again boil for half-an-hour, with the same precautions as before.

At the end of half-an-hour filter as before, through a linen filter, wash with hot water, and finally once with methylated spirit. Scrape off the linen as before, placing the insoluble residue on a watch glass. Dry in the steam oven.

In the second treatment, the boiling with sodium hydrate solution dissolves the plant constituents which the first treatment with acid had failed to attack. The residue which resisted both treatments is cellulose, or, as the analyst prefers to call it, fibre.

A somewhat similar treatment is used commercially to separate cellulose from certain plants. The residue when bleached and spread out into sheets makes paper. In some plants, such as flax, the cellulose, which exists in long fibres, is separated by allowing the rest of the plant to rot in water. This process is known as retting. In the case of the cotton plant, the seeds are provided with long fibres or hairs composed of cellulose, which are separated by mechanical means. Thus the common substances, paper, linen, and cotton, are composed of almost pure cellulose.

Properties of Cellulose.

Cellulose is, as the method of preparation has shown, insoluble in water and in acids and alkalis. It is, in fact, a most stable and permanent substance. Its formula is like that of starch, a large multiple of the simple formula, $C_6H_{10}O_5$. This agrees with its inclusion in the carbohydrate group, which can also be shown experimentally as follows:—

Put a small quantity of cellulose, either that prepared from ground oats or chopped straw, or, perhaps better still, a bit of filter paper or cotton wool, in a small mortar. Pour on to it enough strong sulphuric acid to cover it, and rub with a pestle until the solid substance disappears. Pour into a small flask and add water. Note that the cellulose has practically dissolved. Boil over a small flame for some time, taking out a portion from time to time, neutralising with sodium hydrate and boiling with Fehling's solution. Ultimately it will be found that the continued boiling with acid, after first dissolving in strong sulphuric acid, has transformed the cellulose into sugar. This confirms the inclusion of cellulose in the carbohydrate group.

Fibre.

The cellulose separated from woody or fibrous plants by the method described above is often not pure. It has been partially or wholly changed into a substance called lignin, which is still tougher and more permanent than cellulose. It is for this reason that the analyst does not wish to commit himself to its being cellulose, but prefers to call it fibre.

Cellulose in Crops.

Cellulose or fibre is an abundant constituent of most plants. Hay and straw contain 30 to 40 per cent. Since the annual production of these two in the United Kingdom reaches about 60 million tons, their total cellulose content must amount to between 20 and 25 million tons. It is remarkable that this vast amount of so permanent and insoluble a substance as cellulose should disappear annually. As a matter of fact the disappearance of all this cellulose, and the cellulose of

paper, the leaves of trees, and the remains of other plants is due to the action of certain kinds of microbes, which in the presence of moisture feed upon cellulose and change it into carbon dioxide, water, and a variety of other products, amongst the most important of which is the vegetable matter or humus of the soil.

Gums and Mucilages. Many plants contain carbohydrates which are neither starch, sugars, nor cellulose. Put some linseed in boiling water, and note that the seeds will burst, and that a gummy mucilaginous substance will exude from them and swell up in the water. Pour off some of the gummy liquid and divide it into several portions. To one portion add iodine solution. No blue colour is produced, so the substance is not starch. To a second portion add dilute sulphuric acid and boil for some time. When the solution has become clear, neutralise it with sodium hydrate solution, add Fehling's solution and boil. A red precipitate is produced, showing that the substance is changed into sugar by boiling with acid. It is, therefore, a kind of carbohydrate. Among the sugars which are formed is one which differs from all the sugars which we have studied.

Pentosans. Put some of the gummy solution into a distilling flask and add to it twice its volume of strong hydrochloric acid. Fix the flask over a small flame, and allow the liquid to distil into a test-tube. Moisten a strip of filter paper with aniline acetate solution. Remove the test-tube, and allow a drop of the distillate to fall on this filter paper. An intense rose colour will be produced. This is a characteristic test for sugars which contain only 5 carbon atoms. Their formula is $C_5H_{10}O_5$, and they are called pentoses.

Linseed mucilage bears somewhat the same relation to these pentose sugars as starch does to the sugars with the formula $C_6H_{12}O_6$. It is, therefore, called a pentosan, since on boiling with acid it splits into pentoses.

Pentosans exist in many plants in considerable proportions. Straws contain about 5 per cent., wheat bran considerably more. Somewhat similar substances called pectins are found in fruits. They have the property of making solutions which become semi-solid or jelly-like on cooling. This property is important in the setting of jam. Another well-known pentosan is the gum which exudes from wounds on the stems and branches of cherry and plum trees. All the experiments described above can be repeated with cherry gum.

Pectins.

CHAPTER V.

THE OILS.

That plants contain oils is a familiar every-day fact. Castor oil is one of the unpleasant recollections of our childhood. Olive oil is in everyday use for making salads. Linseed oil is the basis of paints, and every farmer knows that the percentage of oil left behind in the linseed cake, when the linseed oil is pressed out, is an important factor in determining the food value of the cake. Oils are evidently important plant constituents with which we ought to become more familiar.

Different Kinds of Oil.

The name oil is applied to many different substances. Thus, we speak of paraffin oil, turpentine oil, bitter almond oil, and olive oil. Olive oil we know is commonly used for food, and bitter almond oil as a flavour in cooking. Paraffin oil and turpentine we should have no hesitation in pronouncing as inedible, though the former has of late years become a fashionable medicine. Why is it that some of the substances called oils are good for food and others are not? A few experiments will clear up this point.

Pour into separate test-tubes a few drops of each of the oils mentioned above. Add water to each test-tube and shake gently. Note that in each case the oil floats up to the top, showing that it does not dissolve in the water or mix with it, and that it is lighter than water.

Now add to each test-tube a small quantity of ether and shake gently. Note that in each case the oil dissolves in the ether, making a solution which floats on the water.

Allow a drop of each of the oils to fall on a strip of filter paper. Note that it is at once absorbed by the paper, making a greasy transparent mark.

Properties of Oils.

These substances are all called oils because they all possess certain common characteristics by which oils are recognised: they are lighter than water, they do not mix with water or dissolve in it, they dissolve readily in ether, they make a greasy stain on paper. Substances possessing these properties are commonly called oils.

Now place the pieces of filter paper in a warm place. Note that the stain produced by the olive oil remains unchanged, whilst the stains produced by the other oils disappear, because these other oils evaporate readily, whilst olive oil does not. This experiment can be made more precise by actually determining the boiling point. Olive oil will not boil without decomposing. The other oils mentioned boil between 150° and 200° C.

For these reasons olive oil is called a fixed oil, the others volatile oils. It is also worth noting that olive oil is almost free from smell, whilst the other oils mentioned all possess very characteristic odours.

Fixed Oils or Fats.

Of the oils mentioned, only olive oil is valuable as a food, and, although it is rash to generalise on so small a number of instances, it appears that oils which are valuable for food are non-volatile or fixed oils without odour, whilst oils which are not good for food are volatile oils with characteristic odours. The fixed oils like olive oil are called fats. They possess a very characteristic chemical constitution, as shown by the following experiments.

Composition of Fats.

Put about 5 c.c. of olive oil in a large test-tube, and add 20 c.c. sodium hydrate solution. Shake well, until the oil and the watery solution are thoroughly mixed. Although oils will not mix with water they ~~mix readily with water~~ containing sodium

hydrate or other alkalis. Now put the test-tube in a vessel of boiling water, and keep it there until a drop taken out and stirred in water produces no milkiness.

Pour the contents of the tube into a small beaker, neutralise it with dilute sulphuric acid, and add 3 or 4 gm. of finely-powdered common salt. As the mixture cools, a white curdy mass will solidify on the top of the liquid. Remove this, break it up with a glass rod, and wash it with a little cold water. Put a small bit of it in a test-tube, add distilled water and shake. Note that the tube becomes filled with lather.

Dissolve more of the curd by heating in distilled water and filtering if necessary. To a little of the solution add some calcium chloride solution. A white curdy precipitate is formed.

To another portion add some hard water and shake. Note that white curd is formed instead of lather. Lather can, however, be produced by adding enough of the solution.

To a third portion add some finely-powdered common salt. The white curd again rises to the top.

To a fourth portion add dilute sulphuric acid. A milky precipitate separates, and on warming rises to the top, where it forms an oily layer.

Soaps. The fact that the solution lathers when shaken with distilled water, and gives a curdy precipitate with hard water, suggests that the white curdy mass is soap.

To test this dissolve some soap in boiling water, filtering if necessary, and repeat the above experiments. Note that the soap solution behaves in every way like the solution of the curdy mass, which undoubtedly, therefore, is soap.

Olive oil, therefore, when heated with sodium hydrate solution gives soap, and this behaviour is characteristic of all the fixed oils or fats which are good for food.

Glycerol.

Now take the liquid from which the curdy mass of soap was removed, filter it if it is not clear, and evaporate it to dryness in a porcelain dish placed over a vessel of boiling water. It will be necessary to stir the residue as it gets nearly dry in order to get rid of the last traces of water. Most of the residue will consist of the common salt which was added to cause the soap to separate. Common salt does not dissolve in alcohol, and most organic compounds do. Pour a little strong alcohol on the dry residue, stir well, and filter. The common salt will remain on the filter paper. Any organic compound formed when the sodium hydrate converted the oil into soap will probably run through the filter in the alcohol. Put the alcoholic filtrate in a glass dish or small beaker, and evaporate away the alcohol on the water bath. If the whole experiment has been carried through accurately a small quantity of a thick sweet-tasting liquid will remain, which can be identified by appropriate tests as glycerin, or, to give it its real chemical name, glycerol.

Formulae of Fats.

Glycerol is an alcohol containing three hydroxyl groups. Its formula is $C_3H_5(OH)_3$. It is a constituent of all fixed oils or fats which are compounds of glycerol and fatty acids. Thus olive oil consists chiefly of a compound of glycerol and oleic acid with the formula $(C_{17}H_{33}CO_2)_3C_3H_5$. This compound is called glyceryl trioleate, or simply triolein.

When this compound is boiled with sodium hydrate, the sodium hydrate turns out the glycerol and combines with the oleic acid, forming sodium oleate, thus :—

$$(C_{17}H_{33}CO_2)_3C_3H_5 + 3NaOH = C_3H_5(OH)_3 + 3C_{17}H_{33}CO_2Na.$$

Sodium oleate is a soap. It is soluble in water, but separates out in the form of a curdy mass on addition of common salt. When soap is added to hard water, the calcium salts which make the water hard react with the soap, which is a sodium salt, to make insoluble calcium oleate, which separates as a white curdy precipitate. When

sulphuric acid is added to sodium oleate, sodium sulphate is formed, and oleic acid is set free as an oily liquid. Fixed oils and fats always behave in this way when boiled with sodium hydrate, yielding soap and glycerol. They are compounds of glycerol with oleic or other more or less similar acids, which will be met with in the course of our work.

Testing Plants for Fats.

We noted in our earlier experiments that oils dissolved in ether, and it is this property which enables us to test for the presence of oils in plants. Before testing, the plant substances must be dry and finely powdered. Shake with ether small quantities of linseed meal, oat meal, maize meal, and wheat flour in separate test-tubes. Filter through separate filters, and evaporate off the ether in each case over a vessel of hot water, being careful not to have a flame near, as ether and ether vapour are very inflammable. Note the amount of oil left behind in each case. Linseed contains much oil—over 30 per cent.—oat meal and maize meal much less—only about 5 per cent. Wheat flour contains only a trace.

Transfer some of the oil in each case to a strip of filter paper, and note that it makes a greasy transparent mark which does not disappear on warming. The oils contained in linseed, oats, maize, and wheat are, therefore, fixed oils or fats which possess high food values.

CHAPTER VI.

THE PROTEINS.

We have already (Chapter II.) noted that among the complex substances built up by plants are substances like the gluten of wheat which contain nitrogen, sulphur, and sometimes phosphorus, and are called proteins. We have learned also that cellulose forms the supporting parts of the plant's structure, corresponding to the skeleton of the animal, and that starch, sugar, and oils are the forms in which the plant stores up supplies of food for the future. The stores of food include proteins, but the proteins also play another part in the plant's life.

Protoplasm.

When the plant is alive the protein is the chief constituent of its protoplasm or living substance, so that part, at any rate, of the protein which we obtain from a dead plant was protoplasm, or living substance, when the plant was alive.

Proteins are evidently exceedingly important and interesting substances, and we must now proceed to study them.

Composition of Proteins.

For the following experiments we can use some of the wheat gluten prepared in Chapter II., preferably some which has been dried and powdered. Heat a small quantity in a dry test-tube. It chars, owing to separation of carbon, and at the same time gives off steam which condenses to water on the cooler part of the tube. Gluten, therefore, contains carbon, hydrogen, and oxygen, resembling in this respect the carbohydrates and fats.

Mix a small quantity with 5 to 10 times as much soda lime, and heat the mixture in a dry test-tube. Hold a piece of moistened red litmus paper in the fumes which are given

off. The litmus paper is turned blue, suggesting that they contain ammonia. Confirm this by smelling the fumes. Now ammonia is a compound of nitrogen and hydrogen, NH_3, and gluten, therefore, contains nitrogen, differing in this respect from the carbohydrates and oils.

Take a little more gluten in a test-tube, add strong sodium hydrate solution, a few drops of lead acetate solution, and boil. A dark brown colour appears, owing to the formation of lead sulphide, which is almost black. Gluten, therefore, contains sulphur.

If gluten is a fair sample, the proteins are exceedingly complex substances, more complex than the carbohydrates and oils, for they contain not only carbon, hydrogen, and oxygen like the carbohydrates and the oils, but also nitrogen, and sulphur, and phosphorus is often present too. They are, indeed, so complex that, although many proteins have been separated, purified, and analysed, so that we know their percentage composition, we have not yet succeeded in deciding on their chemical formulæ.

Tests for Proteins.

In spite of this, it is possible to recognise the presence of proteins in plant substances by certain tests. Put a small quantity of gluten in a test-tube, add a little strong nitric acid, and warm. The mixture turns yellow. Now add cold water and shake. Pour some ammonia solution into the test-tube, and note that in the upper part of the liquid, where the ammonia is in excess, the colour deepens to orange. This is a characteristic test for proteins, and is known as the xanthoproteic test. It is interesting to find out what the test means. Put a few drops of benzene into a test-tube, add a few drops of strong nitric acid, and heat for a short time. Brown fumes are given off, and a yellow substance is formed, which, on addition of water, gives a yellow milky liquid. Now add ammonia, and note that, as in the case of gluten, the colour deepens to orange. This xanthoproteic test depends on the presence of a benzene ring in the protein

To a little gluten in a test-tube add some Millon's reagent and boil. A red colour or a brick-red precipitate is formed, which again depends on the presence in the protein of a benzene compound known as tyrosin.

Dissolve a little gluten by warming with some strong sodium hydrate solution in a test-tube. Cool and add one drop of dilute copper sulphate solution. Shake the tube, and note that a pinkish violet colour is formed. This test is known as the biuret test, and is a characteristic test for proteins.

This test again has a definite meaning. Heat a little urea in a test-tube. It melts at first, but on further heating solidifies, giving off ammonia. The change which takes place is represented by the following equation:—

$$\underbrace{NH_2 - CO - NH_2}_{\text{urea}} + \underbrace{NH_2 - CO - NH_2}_{\text{urea}}$$
$$= NH_3 + \underbrace{NH_2 - CO - NH - CO - NH_2}_{\text{biuret}}.$$

After the test-tube containing the solid product, which is known as biuret, has cooled, pour some sodium hydrate solution into it, and help it to dissolve the biuret by warming and shaking. Cool again, and add one drop of dilute copper sulphate solution. Shake, and note that a pinkish violet colour is formed. The biuret test, therefore, indicates that some of the atoms of carbon, hydrogen, oxygen, and nitrogen in proteins are arranged as in biuret—

$$NH_2 - CO - NH - CO - NH_2.$$

To a small quantity of protein in a test-tube add some "reduced oxalic acid solution" and pour a little strong sulphuric acid down the side of the tube so that it forms a layer at the bottom. Most proteins cause the formation of a purple ring at the top of the sulphuric acid layer. The purple colour indicates the presence in the protein of an amino acid known as tryptophan.

It is important to note that each of these tests indicates the presence in the protein of a definite group of elements

combined in a definite manner. When a protein is digested by an animal it is split into about twenty separate and distinct compounds called amino acids. These amino acids are formed from the groups of elements recognised by the above tests. From the mixture of amino acids resulting from digestion the animal picks out the amino acids it requires for its own purposes, and it picks them out in certain proportions. If any amino acid is too abundant the excess of it is wasted. If any is deficient the animal suffers.

It is an exceedingly difficult matter to test for all the amino acids in a protein. The above tests, however, will show the presence or absence of several of the important ones: Millons' test tells us if the protein contains tyrosin, the "reduced oxalic acid test" does the same for tryptophan, and the sulphur test for an animo acid known as cystin.

All proteins do not contain all the twenty amino acids. Certain proteins, *e.g.* gelatin and zein, one of the proteins of maize, are deficient in one or two of them. Some proteins contain great excess of some amino acids. Consequently all proteins are not of the same value to the animal. Animal proteins are usually better than vegetable proteins, because on digestion animal proteins yield all the amino acids in about the proportion which the animal requires. In the case of vegetable proteins the safest course is to use a mixture of feeding stuffs, so that the excess of certain amino acids in the protein of one may balance the deficiences of the same amino acids in the protein of others.

Properties of Proteins.

In applying these tests to the discovery of the presence or absence of proteins in certain plants we shall meet with many difficulties. Although proteins contain the same percentage of carbon, hydrogen, oxygen, and nitrogen, and give similar results when tested as above, they differ widely in many of their properties. Some of them are soluble in cold water, but are precipitated or coagulated from their solutions on heating. These are called albumins, from their similarity in these

respects to white of egg, which has long been known to chemists under the name albumen.

Others do not dissolve in pure water, but can be dissolved by water containing a little common salt. These are known as globulins. Like albumins, their solutions are coagulated by heating. Many proteins are known which dissolve neither in pure water nor in salt solution: some of them dissolve in dilute acids, others in dilute alkalis, and still others in alcohol. There are some proteins which are insoluble in all these solvents, and can only be dissolved by ferments, or by acids or alkalis so strong as to decompose them.

Testing for Proteins in Plants.

To make a complete examination of any plant substance for the presence or absence of proteins is evidently a lengthy proceeding, for it involves trying in turns all the solvents mentioned above. We shall only be able to deal with a few comparatively simple instances.

Prepare a quantity of mangold or turnip juice by slicing the roots and passing them through a sausage mill, subsequently squeezing the pulp in a square of fine linen. Boil a quantity of the juice in a beaker, and note that a curdy precipitate separates. Filter or skim this off, and test it by the xanthoproteic test. Note that with nitric acid it gives a yellow colour, which turns orange on addition of water and ammonia. It is, therefore, a protein, and, since it was soluble in the watery juice from which it coagulated on boiling, it must be either an albumin or a globulin.

Put 10 to 20 gm. of finely powdered linseed cake or cotton cake in a flask, and add about 5 gm. of common salt and 100 c.c. of water. Shake for some time, allow to stand, shake again, and repeat the process for several hours. Finally pour the contents of the flask on to a large filter. Test the filtrate as follows:—

Heat a portion in a test tube. Note that coagulation takes place.

Pour a little into a beaker of water. Note that each drop as it falls into the water becomes milky. This is because the protein was dissolved in salt solution, which, as it mixes with the water, becomes so dilute that it can no longer hold the protein in solution.

Test a portion by Millon's test, and by the biuret test. Linseed and cotton seed cakes contain a protein which dissolves in salt solution and coagulates on boiling. It is, therefore, a globulin.

Put 10 to 20 gm. of ground peas or beans in a flask, add 100 c.c. of water and 5 c.c. of sodium hydrate solution. Shake, and allow to stand as before. Pour on to a large filter, and test the filtrate as follows :—

Neutralise a portion by the cautious addition of drops of dilute acid. As it becomes neutral a precipitate appears.

Test a portion by the biuret test.

Beans and peas contain a protein which is soluble in dilute alkalis.

Put about 5 gm. of wheat flour, oat meal, barley meal, or maize meal in a flask, and add 50 c.c. of strong alcohol and 10 c c. of water. Shake, and allow to stand as before. Finally pour on to a large filter, and test the filtrate as follows :—

Pour some of it very slowly into water. As the water dilutes the alcohol a milky precipitate separates.

Test a second portion by the biuret test. If you wish to apply the xanthoproteic test and Millon's test, the alcohol must first be evaporated away. Alcohol would react too violently with nitric acid.

Cereal grains contain proteins which are soluble in 70 per cent. alcohol.

We have now proved the presence of proteins in mangolds, swedes, linseed, cotton seed, beans, peas, and cereals, which is enough to show that proteins are of general occurrence in plants. They are, in fact, usually the next most abundant constituent after the carbohydrates.

CHAPTER VII.

SOME LESS ABUNDANT PLANT CONSTITUENTS.

We have now studied the more abundant constituents of plants, the carbohydrates including starch, sugars, cellulose and pentosans, the oils, and the proteins. Plants, however, contain many other constituents which though less abundant are perhaps not less important.

Oxidations in Plants.

We saw in Chapter II. that the first products of photosythesis were the carbohydrates. We also noted that a portion of the carbohydrates so formed were oxidised or otherwise changed by the plant, so as to provide material and energy for growth, whilst the rest, being probably the greater portion, were stored for future use. To return to the oxidation of the carbohydrates for the provision of material and energy for the immediate purposes of the plant. The ultimate products of this oxidation are carbon dioxide and water as is shown by observation of the respiration of the plant in the absence of light. The oxidation, however, does not take place in one single step: there are probably several intermediate steps between carbohydrate and carbon dioxide. Some of the substances corresponding to these intermediate steps are useful to the plant and can be identified and studied.

Organic Acids.

Prepare some mangold, turnip, or potato juice by the method already described. To a small portion in a test-tube add five times as much strong alcohol, shake well and filter. To some of the clear filtrate add a few drops of phenol phthalein, an indicator which is colourless in presence of acids but turns pink when in contact with alkalis. Note that the solution remains

colourless and is therefore acid. Now add dilute solution of sodium hydrate drop by drop, shaking after each addition. Note how many drops are required to neutralise the acid in solution as shown by the production of a pink colour with the phenol phthalein. Evidently the plant juice contains a measurable amount of acid.

Oxalic Acid. Put some rhubarb stalks through the sausage machine and squeeze out the juice as before. Test a sample of the juice with litmus paper. It is strongly acid. If necessary clear the juice by alcohol as above, and to the clear solution add calcium chloride. Note that a white precipitate is formed which does not dissolve on addition of acetic acid. Rhubarb juice is acid and its acidity is due to the presence of oxalic acid.

Citric Acid. Prepare some lemon juice by cutting the lemons in halves and squeezing. Test the juice with litmus paper. It is strongly acid. Neutralise some of the juice by cautiously adding ammonia solution in the presence of a drop of litmus. Now add calcium chloride solution. No precipitate is formed. The acidity is therefore not caused by oxalic acid. Now boil the solution. A white precipitate is formed. This is a characteristic test for citric acid.

We may conclude that some kind of organic acid is a general constituent of plants although present in varying degrees. The acid has probably been formed by the oxidation of carbohydrates. It is found in the juice, and is useful to the plant, partly because it protects the plant from certain enemies, partly because it may help to dissolve from the soil the salts required by the plant.

Essential Oils. Cut up the remains of the lemons and put them in a large flask with a quantity of water. Connect the flask with a condenser and receiver and boil the water. Note that the water which drips from the condenser into the receiver contains drops of oil. When oil drops no longer come over, pour the whole distillate

into a separating funnel, shake gently and allow to stand while the oil rises. Run out the water and leave the oil. Transfer the oil to a test-tube for examination. The method of separation has shown that the oil is lighter than water with which it does not mix. Note its very fragrant smell. To remove from it the last traces of water, drop into the test-tube a few pieces of calcium chloride and shake. After a few minutes filter through a dry filter. Put a drop of the oil on a strip of filter paper. Note that it makes a greasy transparent mark, which, however, slowly disappears on warming

This oil is therefore an oil according to our definition, but since the mark it makes on paper disappears on warming it is a volatile oil and not a fixed oil or fat having a high food value. This can be confirmed by finding its boiling point. Fit a cork to the test-tube. Bore a hole in the cork to fit a thermometer reading to at least 200° C. Cut a slot out of the side of the cork so that when it is put into the test-tube there may be a vent for the vapour. Put the cork in the tube and adjust the thermometer so that its bulb is well clear of the liquid. Clamp the test-tube and heat with a small flame. The liquid will boil and when its vapour has filled the tube, the thermometer will read about 160° C. which is the boiling point of the oil.

Terpenes.

This oil is called volatile or essential oil of lemon. Such oils are frequently found in plants to which they impart characteristic scents and flavours. They belong to a large class of chemical compounds called terpenes with the general formula $C_{10}H_{16}$.

Aldehydes.

The terpenes are by no means the only class of chemical compounds which impart scents and flavours to plants. Bitter almond oil which gives the scent and flavour to bitter almonds is an aldehyde, called benzaldehyde. Many other scents belong to the class of esters which are salts of organic acids and alcohols. The cruciferae usually owe their sharp taste to oil of mustard, which is a sulphur compound.

Amides. We have seen that the proteins are the most complex of all the constituents of plants. The plant, however, builds them up from the simple substances it takes in from the air and from the soil. The building up process undoubtedly takes place in several stages, which may probably be represented thus. First some of the carbohydrates are oxidised to organic acids, which combine with ammonia, either absorbed as such from the soil, or produced by the plant from nitrates absorbed from the soil. The plant removes water from the ammonium salts thus produced, and the resulting amides are then further combined together to form protein. In fully ripe parts of plants such as seeds the intermediate stages have been passed through and all the nitrogen has been built up into protein. In unripe plants or parts of plants all the stages can be identified, though their identification requires some considerable manipulative skill. Thus the juice of the mangold contains nitrates, ammonium salts, amides, and proteins. We have already shown how to separate the protein by coagulating it by boiling. The nitrates and ammonium salts are difficult to identify. The presence of amides, however, can readily be proved by taking advantage of their property of giving off nitrogen gas when acted on by sodium hypobromite. Add some freshly made sodium hypobromite solution to some mangold juice which has been boiled, filtered, and cooled. Note the effervescence due to the evolution of nitrogen. The amides present in mangolds are glutamin and asparagin. These amides are commonly found in succulent unripe plants. They are half-way stages in the building up of protein.

Ash. Make a small heap of chopped hay on a metal plate. Place the plate on a tripod and heat it with a flame until the hay begins to burn. The organic constituents of the hay will burn, their carbon, hydrogen, oxygen, and nitrogen being converted into gaseous products which disappear into the air. A small quantity of

grey powder remains behind. This is called ash. It represents the substances which the plants of which the hay consists took from the soil, except the nitrogen compounds which are converted into gases on burning.

On testing the ash it will be found to consist of lime, potash, phosphates, sulphates, chlorides, and silicates, together with traces of iron and magnesia, and a variable amount of unburnt carbon depending on the completeness with which the hay was burnt.

We can now summarise the composition of plants as follows :—

Plants contain carbohydrates, which include starch, sugars, cellulose, and pentosans; oils, which include fixed oils or fats, which possess high food value, and essential oils which provide scents and flavours; proteins; and amides which are half-way stages in the building up of proteins; organic acids, aldehydes, and other substances which contribute to the plant's scent and flavour; and finally, inorganic or ash constituents, amongst the most important of which are lime and phosphates.

Vitamines.

There is still one more class of substances contained in plants which must not be overlooked—the newly discovered vitamines. These substances exist in plants in such excessively minute quantities that no one up to the present has succeeded in separating them from the plant or even in devising a chemical test for their presence. We can only conclude that they are present or absent in a diet by observing the effect of the diet on animals which live on the diet for a considerable period.

CHAPTER VIII.

COMPOSITION OF MILK.

So far we have learned that plants consist of water, carbohydrates, oils, proteins, and small quantities of other substances such as amides, organic acids, scents and flavours, and inorganic materials known collectively as ash. Our next step is to find out which of these constituents are important in the diet of animals.

There are various ways in which this problem can be attacked. The simplest for our purpose will be to examine some kind of natural food which forms the exclusive diet of various animals. Milk answers these requirements admirably, for it is the sole food provided by nature for the sustenance of newly born animals at the most delicate and critical period of their life. It may, therefore, be assumed to be a perfect food for the purpose for which it is designed. Whatever substances our examination shows to be present in milk may be assumed to be necessary constituents of a healthy diet. It is not likely to contain anything which is unnecessary, or to be deficient in anything which is necessary.

Albumen.

Pour a small quantity of milk into a porcelain dish, and heat it on a water bath. Note that as soon as the milk gets hot a skin forms on the surface. Evidently the milk contains a constituent which is dissolved in the milk at ordinary temperature but separates and rises to the surface when the milk is heated. Now this is very peculiar behaviour, for most substances dissolve on heating and separate from solution on cooling: this substance was dissolved in cold milk but separated on heating. We know one other substance which behaves in this way—white of egg

—the chemical name of which is albumen. Possibly this skin which forms on heated milk may be albumen.

Albumen is a protein which gives all the protein tests. It is soluble in cold water from which it separates, or coagulates, on heating. Remove the skin from the milk by means of a glass rod, and transfer it to a test tube. Add to it a little strong nitric acid and warm. It turns yellow. Now add water until the test tube is half full, and then ammonia. The yellow colour deepens to orange. This is the well-known xanthoproteic test for proteins. Evidently the skin which separates from milk on heating is a protein—the particular kind of protein known as albumen.

Curdling.

We have now separated and identified one constituent of milk—albumen—a protein. Let us consider our next step. Everyone knows that if milk is kept for some time, and especially if it is kept in a warm place, it becomes sour and curdles. Dip a blue litmus paper into some sour milk and note that the paper turns red. This is what we should expect, for sour is only the popular name for acid. Apparently the acidity which develops in milk on keeping causes the milk to curdle, that is to say, it causes a curdy substance to separate from the milk. Everyone who has tried to heat sour milk also knows that heating hastens the separation of the curd.

Separation of Curd.

Now it is a long process to wait for the milk to become sour enough to curdle, and if we are right in thinking that the separation of the curd is simply due to the milk becoming acid, it should be possible to bring about the separation of curd at once by adding acid, especially if we hasten the process by warming the milk.

Put about 100 c.c. of milk in a beaker and warm it to 50° C. Stir it with a glass rod and add dilute sulphuric acid very slowly, a drop at a time, stirring well between each successive drop. After a few drops have been added curdling will take place, and, if the above directions have been carefully followed,

the whole of the curd will collect in a lump which will stick to the glass rod. Pick out this lump of curd; transfer it to another beaker and wash it several times with cold water. Note that the curd forms a much larger proportion of the milk than the albumen did.

Testing the Curd.

Now to examine the curd. We all know that milk contains butter fat. This may therefore be present in the curd, and we must test for it. We have already learned that the best way to test for fat is to take advantage of the fact that it dissolves in ether. But ether does not mix with water, and the curd is wet. We must, therefore, dry it so that the ether may mix with it. The best way of drying such a substance is to wash away the water it contains with alcohol. Pour some methylated spirit on to the curd, and break it up with the glass rod. Pour off the spirit, add some more and stir the curd again. Pour off the second lot of spirit. The curd will now be practically free from water, and will mix readily with ether. Add some ether and stir well. Pour off the ether through a filter. Add more ether and pour off again. Note that the ether is slightly coloured which shows that it has dissolved something. Pour the ether into a porcelain basin standing over hot water. The ether will very soon evaporate, and leave in the basin a globule of butter fat.

Fat.

Now return to the white powdery curd from which the fat was dissolved by ether. Remove most of the ether by pressing it with a wad of filter paper. Spread it out on a sheet of filter paper and evaporate away the remaining ether by leaving it for a short time in a warm place.

Casein.

Put a small quantity in a dry test-tube and warm it until it is quite free from ether. Heat it in a flame, and note that it chars and gives off water. It contains, therefore, carbon, hydrogen, and oxygen. Heat a second lot in a tube with soda lime, and note that it gives off ammonia. It therefore contains nitrogen, and is presumably a protein.

To a third portion add nitric acid and warm. It turns yellow. Add water and then ammonia. The yellow colour deepens to orange. Evidently it is a protein.

Put still another small portion into a test-tube, add half a tube full of water and a little sodium hydrate solution. Warm slightly and shake. Note that the substance dissolves, forming a more or less turbid solution. Add dilute sulphuric acid drop by drop, shaking between each addition. After a few drops of acid have been added the substance again separates as a white curdy precipitate.

Our experiments have therefore shown that the curd which separates from milk on addition of acid consists of a mixture of butter fat, and a protein which is dissolved by alkali and precipitated (or curdled) again by addition of acid. This protein is known as casein. It is so called because cheese is made from the curd of milk, and the Latin word for cheese is caseus.

Milk Sugar.

We have now identified as constituents of milk two proteins, albumen and casein, and a fat—butter fat. So far we have not found a representative of the class of carbohydrates. We have not, however, examined the liquid from which the curd separated. Filter some of this liquid and add just enough sodium hydrate solution to make it alkaline. Now add some Fehling's solution and boil. Note that the blue colour disappears and a red precipitate is formed. The liquid therefore contains sugar, a carbohydrate.

Milk, therefore, contains representatives of the three great classes of chemical compounds which we have found to be the main constituents of plants, namely the proteins, represented by albumen and casein, the fats and oils represented by butter fat, and the carbohydrates represented by milk sugar.

In addition to these constituents milk also contains two other substances.

Water.

Put some milk into a flask fitted with a cork through which passes a thermometer. Cut a slot in the side

of the cork. Place the flask over a flame and allow the milk to boil. Note that when the milk boils steam issues through the slit in the cork and the thermometer stands at 100° C. the boiling point of water. Evidently milk contains water.

Ash. Evaporate some milk to dryness in a porcelain dish over a water bath. Transfer the dried milk to a small porcelain crucible, and place it on a pipeclay triangle over a flame. The protein, fat, and sugar will soon burn away. Note that a small quantity of greyish incombustible material remains. This is the ash. Pour a few drops of nitric acid on to the ash and wash it from the crucible into a test-tube. Note that the ash dissolves in the acid with the possible exception of a small quantity of carbon due to incomplete burning.

Calcium. Divide the solution into two parts. To one part add ammonia to neutralise the nitric acid, and citric acid to redissolve the precipitate which results from neutralisation. Now add a few drops of ammonium oxalate solution. A white precipitate will appear showing that the ash of milk contains calcium.

Phosphate. To the second portion add ammonium molybdate solution and warm. A yellow precipitate will appear showing that the ash contains phosphoric acid.

Summarising the results of our examination we have shown that milk contains proteins, fat, carbohydrate, water, and ash, and we conclude therefore that these substances are the necessary constituents of the diet of animals.

Since our examination of plants showed that they contained these same substances, we can now understand why plants are commonly used to feed animals.

CHAPTER IX.

THE ANALYSIS OF FEEDING STUFFS.

Necessary Constituents of Animal Diet.

The experiments which we made in the last chapter showed that milk consists of certain proteins, fats, and carbohydrates, together with certain inorganic or ash constituents, suspended or dissolved in water. From this fact we argued that, since milk is the food designed by nature for the young of most of our animals, these substances, proteins, fats, carbohydrates, ash, and water are the necessary constituents of a complete diet.

The experiments we carried out were what are known as qualitative experiments: that is to say, they were designed to ascertain the quality, or kind, of constituents present in milk, and they took no account of the quantity of these constituents.

By more precise methods it is possible to make a quantitative analysis of milk so as to ascertain the percentage of each constituent. Such quantitative analyses in the case of very *large numbers of samples show that the average composition* of cow's milk is as follows:—

Average Composition of Cow's Milk.

	Per cent.	Per cent.
Albumen	½	
Casein	3	
Total protein	3½	3½
Fat		3½
Milk sugar		4½
Ash		¾
Water		87¾

To carry out an analysis of this kind requires considerable manipulative skill and experience, such as it is impossible for every one to acquire. By carrying out the following simple experiments, however, it is possible for anyone to impress upon his memory many important facts about the composition of the common feeding stuffs. It will be convenient to consider first home-grown feeding stuffs in the following order:—Straw, hay, roots, green stuffs, cereal grains, leguminous grains. Afterwards we will turn our attention to the feeding stuffs which we purchase to make up the deficiencies of those we grow ourselves.

Straw.

Straw is the residue left when the grain is separated by thrashing from a cereal, leguminous, or other crop. Thus we have wheat straw, barley straw, bean straw, and so on. The thrashing machine, however, does not deliver all the straw together. The main bulk, which is commonly called straw, is tossed out by the shakers, and is almost invariably preserved by stacking or in some other way.

Two other products are thrown out at the side of the machine, namely, the chaff, which consists of the glumes, pales, awns, etc., of the grain, and the cavings, which consist of short pieces of broken stems, leaves, pods, etc. Both chaff and cavings are very frequently wasted. In considering the composition of straw it is, therefore, necessary to pay attention to the straw of different kinds of crops, and to the value not only of the straw, but of the chaff and cavings.

For our experiments we will use, in the first place, some wheat, barley, or oat straw which has been finely chopped or ground in a mill.

Testing for Proteins.

1. Counterpoise a small square of paper by a similar square from which you snip bits until the two are of equal weight. Put one on each pan of the balance. In the left-hand pan of the balance put a ½ gm. weight. Put ground straw on to the paper in the other pan until the pans swing level. Now remove the

$\frac{1}{2}$ gm. weight and replace it by 3 gm. Put soda lime on to the paper holding the straw until the pans again swing level. Remove the paper which will now hold $\frac{1}{2}$ gm. straw and $2\frac{1}{2}$ gm. soda lime. Mix these well and pour them into a test-tube through a roll of paper, which acts as a funnel and keeps the mouth of the tube clean. Tap the tube so as to get the mixture to the bottom, and heat it in the flame. Hold near the mouth of the tube, in the escaping vapour, a piece of moistened red litmus paper. Note that after a time the paper shows signs of turning blue in places. This shows that a very little ammonia is given off. The straw, therefore, contained a very little nitrogen, and, since nitrogen is a characteristic constituent of protein, the straw evidently contains very little protein.

Testing for Fat.

Put a small quantity of ground straw into a dry test-tube and add some ether. Close the tube with your thumb, and shake well for some time. Pour off the ether, through a filter if necessary, into an evaporating basin, and allow the ether to evaporate by standing the basin on a vessel of hot water, not over a flame, because ether takes fire so readily. When all the ether has evaporated, note that only a small trace of oily residue remains. Straw evidently contains very little oil or fat.

Testing for Fibre.

Weigh out 2 gm. of straw as before, and transfer it to a beaker. Add 25 c.c. of dilute sulphuric acid and 175 c.c. of water. Stand the beaker on a wire gauze over a flame, covering it with a clock glass. As soon as it begins to boil, adjust the flame so that it continues to boil gently for about half-an-hour. At the end of this time pour off some of the liquid for further tests, and note carefully the amount of material undissolved.

The undissolved material represents roughly the amount of cellulose, or, as the analyst calls it, woody or indigestible fibre in the straw. Note that it forms a very large proportion of the straw, somewhere between a third and a half. When it has settled, pour away the liquid and wash the fibre

into a test-tube. Label it and keep it for comparison with the fibre from other feeding stuffs.

Testing for Carbohydrates. In an earlier chapter we found that all the ordinary carbohydrates like starch and pentosans were transformed by boiling with acid into sugars which are readily soluble. If the straw contains carbohydrates, therefore, we should expect to find them in the acid liquid. To test this liquid proceed as follows:—To a portion of it in a test-tube add just enough sodium hydrate solution to neutralise its acidity, testing for this point by a bit of litmus paper dropped into the tube. When neutral or faintly alkaline, pick out the litmus paper and add enough Fehling's solution to produce a deep blue colour. Boil, and note that the blue colour disappears, and is replaced by a red precipitate, which shows the presence of a considerable amount of sugar. The straw must, therefore, have contained a considerable proportion of carbohydrates, which were converted into sugar by boiling with dilute acid.

Testing for Ash. Put a small quantity of ground straw into a porcelain crucible, and place the crucible on a pipe-clay triangle over a flame. The straw will soon burn away. Note that a considerable amount of ash remains. When cool, pour on to the ash a little strong nitric acid and a few drops of water. Warm the crucible, add more water, and wash the contents of the crucible into a test-tube. Note that a considerable amount of insoluble material settles out. Pour off the clear solution into another test-tube for examination later. Stir the insoluble residue with a glass rod, and note that it feels hard and gritty. It is, in fact, silica. Divide the clear liquid into two parts. To one part add ammonium molybdate solution and warm. Note that only a very small amount of yellow precipitate is formed, showing that the ash of straw contains very little phosphate. To the other part add ammonia until alkaline, then a little citric acid solution to dissolve any precipitate which may have been

formed, and, finally, ammonium oxalate solution. Note that only a very small amount of white precipitate is formed, showing that the straw contains very little lime.

Composition of Straw.

Our experiments show that straw is a bulky fodder containing much indigestible fibre, to which it owes its bulk, a good proportion of digestible carbohydrates, very little oil, and very little protein. It contains a fair amount of ash, which, however, is rich in silica and poor in the two ash constituents required by animals, namely, phosphates and lime.

For the exact composition of straws of various kinds readers are advised to consult the tables given in *Rations for Live Stock* (Miscellaneous Publication, No. 32) which can be obtained from the Ministry of Agriculture.

It is not desirable to attempt to memorise all the figures given in these tables, because they can be consulted whenever occasion requires. There are, however, certain salient facts about the composition of straws which everyone concerned in the feeding of live stock should know.

Oat Straw.

Oat straw is a more valuable fodder than either wheat straw or barley straw. The reason of this is as follows:—Oats are commonly cut before they are dead ripe, and this is especially so in the North of England and Scotland. One of the essential factors in ripening is the transfer of materials from the straw to the grain. This process is not so complete in oats as in wheat and barley. Oat straw, especially in the North, therefore, contains more protein and soluble carbohydrates than wheat and barley straw, and this increases its nutritive value.

Wheat Straw.

Wheat straw is stiffer and more elastic than either oat straw or barley straw. For this reason it makes better litter and worse fodder.

Barley Straw.

Barley straw often contains a considerable proportion of the leaves and stems of the clovers and grasses which are commonly sown with the barley. These leaves and stems are young, and have not been robbed

by seed formation. Their nutritive value is, therefore, high, and barley straw enriched in this manner is, therefore, good fodder.

Chaff and Cavings.

It has been pointed out above that the thrashing machine delivers the straw in three parts—the straw proper, the cavings, and the chaff. These three products differ greatly in nutritive value. The straw proper consists of the stems and the tougher leaves, and is good for litter. The cavings consist of the more breakable leaves, and are usually very rich in clover leaves if these are present in the crop. They make poor litter, but their nutritive value is comparatively high. The chaff also has a high nutritive value, but it is liable to irritate the eyes of animals to which it is fed. This defect can, however, be remedied by mixing it with pulped roots 24 hours before use, so that the moisture in the roots may soften it.

Bean and Pea Straw.

Bean, pea, and vetch straw has a high nutritive value. The stems are, however, tough and indigestible, the best parts being the leaves and pods.

Hay Composition.

If we repeat with ground or finely-chopped hay the same series of experiments which were applied to straw above, we shall find by comparison of the results obtained that hay is similar to straw in that the presence of a high proportion of indigestible fibre gives it great bulk. It also resembles straw in containing much digestible carbohydrates, very little oil, and a fair proportion of ash containing much silica. It differs from straw in containing very much more protein, and its ash contains more phosphate and lime.

Quality of Hay.

Readers should again consult the tables in *Rations for Live Stock.* From these tables it will be seen that hay is very variable in composition. The reasons for this variation are three in number. Firstly, the botanical composition of the herbage from which the hay is made. Broadly speaking, the more clover the hay contains,

the higher its content of protein, the lower its content of indigestible fibre, and the better its quality.

Date of Cutting. Secondly, the date of cutting affects the quality. As the spring and early summer advances the total weight of hay which can be saved from a given area increases at first rapidly, but the rate of increase gets slower and slower as time goes on until flowering time. After this date growth almost ceases, and the plants devote their attention to the transfer of digestible materials from the leaves and the stems to the seeds. Now the seeds are very liable to get lost in the process of making and saving the hay. The plants have robbed their stems and leaves in forming their seeds. Consequently hay which has gone to seed contains little digestible proteins and carbohydrates and correspondingly much indigestible fibre, and is poor in quality. To obtain the best result, hay should be cut when the majority of the plants in the herbage are just coming into flower, provided, of course, that weather conditions are favourable. Further delay will give very little more hay, which will be much inferior in nutritive value.

Lastly, the quality of hay is dependent on the weather at haymaking time. Rain washes some of the soluble nutritive materials out of the hay, and diminishes its food value. Excessive exposure to sun bleaches the hay, and diminishes its aroma and palatability.

CHAPTER X.

GREEN FODDERS.

Amongst green fodders are included grass, which is by far the most important in point of quantity, tares or vetches, alone or in mixtures, lucerne, sainfoin, kale, rape, and the other numerous crops, other than roots, which are consumed on the land in the green state.

Grass.

Taking grass as typical, the following experiments will serve to show the most important points to note as to the composition of green fodders.

Estimation of Water.

Weigh a small flat porcelain dish, or better still an aluminium tray. Spread out in it a thin layer of freshly cut grass which has been chopped or snipped with scissors into short lengths. Weigh again and record the weight of grass taken.

Thus	Weight of grass + dish	55·72	gram.
	Weight of dish alone	43·25	,,
	Weight of grass ...	12·47	,,

Now place the dish or tray in a steam oven, or on a hot plate kept at about 100° C., and leave it there for 24 hours. Weigh again:—

Weight of dry residue + dish	46·99	gram.
Weight of dish alone	43·25	,,
Weight of dry residue ...	3·74	,,

From these figures it appears that 12·47 gm. of grass when completely dried leaves 3·74 gm. of dry residue. The difference, 8·73 gm., is the water which was evaporated during drying. Grass therefore contains 8·73 × 100 ÷

12·47 = 70 per cent. of water. This high percentage of water is characteristic of all green crops. The percentage is not always exactly 70. It may be as low as 65 or as high as 80, according to circumstances, but it is always high. It is for this reason that green crops are often called succulents.

Testing for Protein.

Transfer a little of the dried residue of the grass to a dry test-tube: add some soda-lime and heat in the flame. Test for ammonia in the evolved gases by means of a piece of moistened red litmus paper. Note that the paper quickly turns blue, which means that ammonia is given off rapidly. This indicates that the grass contains a fair proportion of nitrogenous substance, probably protein. In this, as might be expected, the dry matter of grass resembles hay, as indeed it does in other respects, for hay is of course sun-dried grass. Grass therefore contains about 70 per cent. of water: when most of this is removed, the dry residue which remains is like hay, fairly rich in protein, carbohydrates, fibre, and ash, but very poor in fat.

Composition of Pasture Grass.

There is, however, one very important respect in which grass as grazed by animals should differ from hay. The essence of good management of grazing land is so to stock the land that the grass never grows long and coarse as it does if set up for hay. The animals should therefore feed all the time on young freshly grown grass. Now such grass contains more protein, more soluble carbohydrates, more ash, and less fibre than grass ripe for cutting. It is, therefore, more nutritious and more digestible than is hay. At the same time there is not so much of it, for keeping the grass short diminishes its leaf area, and the leaves are the organs which enable the plant to absorb the energy of sunlight which it uses to build up its substance. Good grazing therefore yields less produce than haymaking, but the produce is more nutritious and more digestible.

The herbage of ordinary grass land consists of grasses,

clovers, and weeds, and of these the grasses predominate. By good management the weeds should be kept at a minimum. By suitable manuring, notably with basic slag, the proportion of clovers can be considerably increased. This increases the value of the herbage, for clovers contain about twice as much protein as grasses, and appreciably less fibre.

Losses in Haymaking.

It was stated above that grass dried in the oven was in most respects similar to hay. This is only correct when the hay has been saved under exceptionally advantageous circumstances—usually the process of haymaking entails very considerable losses. Rain or even heavy dew washes away some of the soluble, and therefore the most digestible and valuable constituents of the grass. Sunlight bleaches the hay, and causes loss of colour, loss of aroma, and it is said destroys some of the vitamines. Rough handling breaks and scatters the more brittle constituents of the hay, usually the leaves of the clovers, and since these are the most nutritive parts of the hay, serious loss may arise from this cause.

Crucifers.

Green crops, other than grass, may be considered under two heads, viz., cruciferous crops and leguminous crops. Cruciferous green fodder crops include kale of various kinds, rape, and mustard. All these crops are commonly grazed on the land where they are grown. Swedes, turnips, and cabbages, which are also cruciferous crops, are usually fed at the homestead or allowed to ripen before they are consumed on the land. They will be considered under the heading of root crops in a later chapter. Dry some freshly gathered mustard or rape in the manner described above for drying grass. It will be found to contain from 80 to 85 per cent. of water. Such crops contain more water, and are even more succulent than grass. Their dry matter is rather different in composition from the dry matter of grass. In protein content the difference is small, but the proportion of soluble carbohydrates is greater, and the proportion of fibre less. Such crops are there-

fore more digestible and more suitable for fattening animals.

Legumes.

Leguminous fodder crops include clovers, lucerne, sainfoin, and tares or vetches. Like the cruciferous fodder crops they contain more water and are more succulent than grass. In content of fibre they resemble grass, but in protein they are considerably richer. To get the best results they should be grazed when young. Their growth ceases at flowering, after which period they transfer their nutritive materials from their leaves and stems to their seeds.

Vitamines.

One of the most valuable characteristics of all green crops is that they contain vitamines, and perhaps this is a convenient place to make a short digression on this subject.

Until about 15 years ago it was assumed that a suitable mixture of proteins, fat, carbohydrates, water, and ash formed a complete diet for all animals. About this date, however, several experimenters endeavoured to rear young rats on such a diet using carefully purified materials in its composition. In every case it was found that although the young rats lived for some time on this diet, growth practically ceased, and they almost invariably became affected with a disease attacking their eyes and ears, and at the same time their nervous system ceased to be able to control their limbs. The addition to their diet of a trace of fresh milk or yeast or plant juice or green food at once caused normal growth to be resumed and relieved the eye and ear disease and the nervous derangement. The explanation suggested was that young animals require something in their diet besides proteins, fats, carbohydrates, water, and ash, and that this something is contained in sufficient amount in milk, yeast, and most fresh green plants.

Further experiments on the same lines have confirmed this suggested explanation, and the existence in many fresh materials of this necessary something is now almost universally recognised.

Later experiments have shown that there are several such substances, some of which are necessary for growth, others for the maintenance of health. At first the name accessory food factors was suggested for these substances, but this has been generally discarded in favour of the more euphonious name of vitamines which was suggested by one of the later experimenters.

The whole idea is so fascinating, and the name vitamines has so romantic a sound, that it has caught the popular imagination and there are signs that it is being exploited in many directions.

It is desirable, therefore, that those concerned with the feeding of animals should be acquainted with the fundamental facts.

So far as is known at present there are three or perhaps four or five vitamines. These are (i) a vitamine invariably associated with fats or oils, generally known as the fat soluble A vitamine, (ii) a vitamine which is found in plant juices and is known as water soluble B vitamine. These are the two vitamines whose absence from the diet of young animals causes cessation of growth and liability to disease.

(iii) The antineuritic vitamine, which exists in the outer skin of the cereal grains, but not in the starchy interior, especially in the case of rice. The absence of this vitamine causes the disease known as beri-beri, or polyneuritis, in certain eastern races who feed almost exclusively on "polished" rice. It is not certain whether this vitamine is identical with water soluble B vitamine.

(iv) The antiscorbutic vitamine, found in most fresh green plants and especially in crucifers such as cabbage. Lack of this vitamine causes the disease known as scurvy, which was one of the chief troubles of sailors and explorers who were compelled in past times to exist for long periods without fresh vegetable food.

(v) The antirachitic vitamine, found in association with fats and oils, which may be identical with the fat soluble A

vitamine. Lack of this vitamine is one of the causes of the disease known as rickets which attacks babies and young animals.

It appears probable that animals cannot make any of these vitamines, and that all of them are made by green plants in the first instance. Animals, however, eat green plants and may store one or other of the vitamines in their tissues and especially in their fat. It is in this way that vitamines occur in milk. Even in the case of cod liver oil, which is notably rich in fat soluble vitamine, the original source of the vitamine is the small green plants which float in the sea.

It appears therefore that farm animals which have access to grass or other fresh green stuff are not likely to develop any of the ills that arise from lack of vitamines. Further than this, anyone who has experimented on this subject cannot help being impressed with the very great difficulty experienced in designing a diet for his experimental animals which can be depended upon to produce the symptons of vitamine deficiency. Putting these two facts together, it appears exceedingly improbable that lack of vitamines is a frequent source of trouble among farm live stock. And in addition it must be remembered that whilst, undoubtedly, healthy normal growth is hindered by the absence of vitamines, it is quite impossible in the absence of a proper ration of proteins, fats, carbohydrates, ash, and water, for none of which are vitamines in any sense a substitute. Animals on a well-balanced and sufficient ration with access to green stuff will not suffer from vitamine deficiency. If they fail to thrive, the cause is much more likely to be bad management.

Nevertheless cases do sometimes occur in which failure to thrive is probably due to lack of vitamines. Slow growth and susceptibility to disease in young stye-fed pigs is often cured by the addition of fish meal, blood meal, dried yeast or green stuff to their diet. Cod liver oil often increases the growth rate of calves reared on milk substitutes.

CHAPTER XI.

ROOT CROPS.

The systematic culture of root crops, which became general in Great Britain not much more than a century ago, has had two widespread results on the farming practice of the country. The fact that roots are sown in the late spring or early summer, and that interculture is possible throughout the summer between the widely separated rows, has made it possible to use them as cleaning crops, and to discard the old practice of fallowing. Secondly, roots keep well throughout the winter, providing succulent fodder for live stock at this season, and making it possible for the farmer to maintain during the winter a continuous supply of fresh meat and milk.

It is with the use of roots for this purpose that we are at present directly concerned, and to enable us to discuss the point, we must first study their composition.

Sampling.

Investigations on the composition of root crops have shown that roots are liable to very great variation. Individual roots of the same variety, grown in the same field with the greatest attainable uniformity in cultivation and manuring, vary in composition to the extent of over 50 per cent. Even a single root is by no means the same all through: the underground part is usually much richer in food substances and poorer in water than the part which grows above ground. If we want to ascertain the composition of the roots growing on a field, it is evidently at least as important to know how

to take a representative sample as it is to learn how to make the analysis.

In order to allow for the individual variation it is necessary that the sample should consist of at least fifty roots of average size taken from different parts of the field or plot. Each of these should then be sampled by cutting out a core with an instrument like a cheese taster, which should be pushed through the root horizontally at its widest part. The sample will then consist of fifty cores and may be relied upon to be representative of the whole crop.

Estimation of Dry Matter.

To examine the sample, proceed thus: place the cores side by side and cut the whole bundle in half. Place fifty half-cores in a flat dish which has been weighed. Place the dish on a hot plate kept at about 60° to 70° C. and leave it there for 24 hours. Now cover it with a sheet of iron or asbestos, supported so that there is a space between the dish and the sheet. Leave for a second 24 hours. Remove the dish to the balance pan whilst still warm and weigh rapidly. Calculate the percentage of dry matter thus :—

Weight of dish + cores	185·7 gm.
Weight of dish	103·2 gm.
Weight of cores	82·5 gm.
Weight of dish + dried cores	112·9 gm.
Weight of dish	103·2 gm.
Weight of dry matter	9·7 gm.

$$\text{Percentage of dry matter } \frac{9{\cdot}7 \times 100}{82{\cdot}5} = 11{\cdot}8 \text{ per cent.}$$

Extraction of Juice.

As soon as the first half sample has been put to dry, pulp the second half sample by putting it through a sausage mill. Tie up the pulp in a piece of linen and squeeze out as much juice as possible.

Test this juice as follows :—

Boil a little of it in a test-tube, and note that there is a small amount of coagulum which sticks to the sides or rises to the top. This shows the presence of a little protein.

Testing for Proteins.

Filter this boiled juice, cool it, and add some freshly-made sodium hypobromite solution. Note the evolution of nitrogen gas which indicates the presence of "amides" which are half-way stages in the building up of proteins.

Testing for Amides.

Clear a second portion of the juice by adding a few drops of basic lead acetate solution which precipitates the proteins and most of the colouring matters. Test some of the clear filtrate for sugar by boiling it with Fehling's solution. Repeat the test on a second portion after first boiling it with a little hydrochloric acid, and neutralising the acid with sodium hydrate solution before adding the Fehling's solution. Note that swedes and turnips contain a mixture of sugars, and that mangolds and sugar beet contain nearly pure cane sugar if sampled before Christmas, but a mixture of sugars in the spring. Refer back to Chapter III. for explanation of these tests.

Testing for Sugar.

You will have noticed that when first expressed, the juice was quite light coloured, but that on standing, its colour darkened very rapidly, especially near the surface where it was in contact with the air. Roots contain a ferment or enzyme of the particular kind known as oxidase. When the cells are burst by grinding, this ferment escapes into the juice. It causes the oxygen of the air to combine with certain "amides" contained in the juice, converting them into a dark coloured substance which in time settles down to the bottom of the vessel in which the juice is contained. A similar action takes place when cut surfaces of apples or other fruits or vegetables are left exposed to the air.

Presence of Oxidase.

These tests will serve to show the salient facts about the composition of such roots as mangolds, sugar-beet, turnips, swedes, and kohl rabi, and even cabbages may be examined by this method. All these crops contain from 9 to 14 per cent. of dry matter. About two-thirds of the dry matter consists of sugars, the rest being chiefly other carbohydrates known as pectins, a little protein, some fibre, and some ash. Broadly speaking, these root crops are very succulent, *i.e.*, they contain much water, and their chief food value lies in the large proportion of carbohydrates which they contain.

Composition of Roots.

In examining potatoes by the same method, you will note that the juice deposits a white powder in considerable quantity. Collect a little of this powder, boil it in water, and note that it swells up and behaves like starch. Cool the solution and show that it is starch by adding iodine solution. You will also find that the percentage of dry matter in potatoes is very much higher—usually just over 20per cent.

Potatoes.

Testing for Starch.

Potatoes differ considerably in composition from other root crops: they contain from 18 to 25 per cent. of dry matter, of which the predominant constituent is starch. Although they contain starch instead of sugar, starch is also a carbohydrate, and potatoes, like other root crops, are essentially a predominantly carbohydrate supplying food.

Composition of Potatoes.

Although sugar beet are seldom grown for feeding animals, it may be advisable to explain certain special points about their analysis, for sugar beet culture seems to be spreading in this country, and what is more, their sugar content is frequently taken into account in dealings between growers and factories.

Sugar Beet.

Sugar beet, like other roots, are subject to great individual variation. Consequently, reliable samples cannot be obtained from less than 50 roots. In coring these roots, which are spindle-shaped, the core should

Sampling.

be taken diagonally through the centre of the root, beginning at the shoulder.

In examining the cores, it is not necessary to determine the dry matter which, although a good measure of food value, does not give much information about the main point at issue, which is the sugar content.

Solids in Juice.

Proceed, therefore, to pulp the whole of the cores, and to squeeze out as much juice as possible. Pour this juice at once into a tall vessel, and float in it an instrument known as a Brix spindle. This is a kind of hydrometer, but its graduations, instead of giving specific gravity, give the percentage of total solid matter in the juice. Thus, if the surface of the juice is level with the reading 19·8 when the spindle is floating freely in the juice, the juice contains 19·8 per cent. of solid matter.

If a Brix spindle is not available, the same result may be obtained by the following rather more troublesome process. Weigh a small flat porcelain dish, measure into it 10 c.c. of juice, and place the dish in the drying oven. All the water will evaporate and the solids will be left in the dish. Weigh again and calculate as follows:—

Weight of dish	8·75 gm.
Weight of dish + solids ...	10·73 gm.
Weight of solids	1·98 gm.

∴ 10 c.c. juice contains 1·98 gm. solids and 100 c.c. 19·8 gm.

Estimation of Sugar.

The next step is to estimate the percentage of sugar in the juice. For this purpose pour 50 c.c. of the juice into a 100 c.c. measuring flask, add 5 c.c. basic lead acetate solution, and fill up with water to the 100 c.c. mark: shake gently and leave until the precipitate of lead compounds of the protein and colouring matters shows signs of settling. As soon as this takes place, pour on to a large dry filter. Throw away the first few drops of filtrate, and then place under the filter a perfectly clean

20 cm. saccharimeter tube. Wash the tube out once with the filtrate, and replace it. When quite full remove the tube and slide on the glass end plate so as to avoid the inclusion of air bubbles. Screw on the cap tightly, and wipe the outside of the tube and the end plates.

The percentage of sugar can now be read in the saccharimeter, which is an instrument very complicated in construction but very simple in use.

First test the instrument to ensure that its zero is correct. Light the incandescent burner. Place your eye to the eye-piece and manipulate the slide of the eye-piece until the field of view is sharply defined and in focus. You will note that this field of view includes an illuminated circle which is divided into three vertical strips. The centre strip may be light or dark and the outer strips dark or light. With your eye still at the eye-piece, rotate the circle near the eye-piece until the illuminated circle becomes the same colour all over, until in fact you cannot distinguish the separate strips.

Now read the position of the pointer on the rotating circle. It should be 0° if the instrument is correctly adjusted. If it is not exactly 0° repeat your observation several times, and average your results. Thus: + ·2, + ·1, + ·2, – ·1, – ·2, 0, – ·1 : these add up to + ·5 – ·4 = + ·1, which divided by 6, the number of observations, is only ·017 which is negligible. Your failure to read 0° every time was evidently due to your unfamiliarity with the instrument and not the fault of incorrect adjustment. To get an accurate result it is clearly advisable for you to take a series of readings and average them.

Now place the filled tube in the trough of the instrument and replace the cover. Again focus the eye-piece and then proceed to turn the rotating circle until, as before, the illuminated circle in your field of vision looks the same all over. Read the position of the pointer on the rotating circle, displace the rotating circle and read again at least six times. Average your results thus :—

Readings: 30·5, 30·7, 30·9, 30·6, 30·7, 30·8. These add up to 184·2, which divided by 6, the number of readings, gives an average of 30·7.

To convert this average reading into percentage of sugar multiply by ·2605 which is the factor of most modern saccharimeters. Thus: 30·7 × ·2605 = 8·0 per cent. sugar. This is the percentage of sugar in the solution contained in the saccharimeter tube, and since in making that solution 50 c.c. of sugar beet juice was diluted with basic lead acetate and water to 100 c.c., the percentage in the juice must have been $8 \times \frac{100}{50} = 16$ per cent.

The sugar beet juice has now been shown to contain (in 100 c.c.) 19·8 per cent. of solids and 16 per cent. of sugar. The percentage of sugar contained in the solids of the juice is therefore

$$\frac{16 \times 100}{19 \cdot 8} = 80 \cdot 8 \text{ per cent.}$$

Quotient of Purity.

This figure, 80·8, is known as the quotient of purity. It is really the percentage of sugar contained in the solid matter of the sugar beet juice. The higher it is the easier the factory finds the task of separating pure sugar from the juice. It should be 80 or over.

Composition of Sugar Beet.

The percentage of sugar in the juice was found to be 16, but the roots are not all juice. They contain 4 per cent. of insoluble fibrous material, which leaves 96 per cent. of juice. Consequently, 100 parts of root, containing 96 parts of juice will contain $16 \times \frac{96}{100} = 15 \cdot 4$ per cent. of sugar. The result of our analysis is, therefore, to show that the given sample of sugar beet contained 15·4 per cent. of sugar, and that the quotient of purity of its juice was 80·8. These are the two figures which govern the value of the sugar beet to the factory.

Although the analysis of sugar beet has taken some time to describe, and although it involves the use of complicated and expensive instruments, it is quite easy to perform, and a skilled analysist will carry out very large numbers of analyses in a very short time.

Sugar Beet Slices.

The residue remaining after the sugar has been extracted from the sliced beets is dried and sold—usually to the farmers who supplied the beets to the factory. These dried sugar beet slices still contain much soluble carbohydrate, some protein, and much indigestible fibre. They should be used as a substitute for roots, for which purpose they are moistened with water, which they soak up readily. Feeding trials have shown that one stone of dried slices can take the place of one cwt. of roots. They are not suitable for use in place of corn, meal, or cake.

CHAPTER XII.

THE CEREAL GRAINS AND THEIR PRODUCTS.

The cereal grains include wheat, barley, oats, and rye which are grown in this country, and maize and rice which are imported from warmer climates. Their products include miller's offals, the portions of the wheat grain rejected in the process of flour milling; brewer's grains and malt culms, which are refuse materials in the brewing and malting industries, and small amounts of materials resulting from the manufacture of oatmeal, pearl barley, cornflour, and such like articles of human food.

Testing Cereals.

Taking oatmeal as typical of the cereals, the following experiments will serve to demonstrate the general facts about the composition of this class of feeding stuffs. Mix a little oatmeal with soda lime, put the mixture into a dry test-tube, and heat it in a flame. Test the evolved gases with a piece of moistened red litmus paper. Note that there is a considerable evolution of ammonia, showing that oats contain a fair proportion of nitrogen. Since in well ripened seeds practically all the nitrogen exists in the form of protein, this means that oats contain a fair proportion of protein.

Proteins.

Starch.

Moisten a little oatmeal with water and stir it into a paste. Pour boiling water on to it, stir it up, and boil. Note that much of the oatmeal swells up and dissolves to form a rather thick solution which goes almost solid on cooling. This suggests the presence of much starch. Confirm by adding iodine solution to a little of the

cooled thick pasty solution and noting the deep blue colour. Starch is evidently the predominant constituent of oats.

Fat. Shake up a few grams of oatmeal with ether in a test-tube, closing the open end with the thumb. Pour on a filter, allowing the ethereal solution to run into a porcelain dish. Place the dish on a vessel of hot water to evaporate the ether, and note that an appreciable oily residue remains. Oats therefore contain quite an appreciable percentage of oil.

Fibre. Put 1 gm. of oatmeal in a beaker. Add 25 c.c. of dilute sulphuric acid and 175 c.c. of water. Place on a gauze over a flame and raise to boiling. As soon as boiling commences adjust the flame so as to maintain the contents of the beaker at the boiling point without allowing them to boil over. Boiling should continue for half an hour and the residue should be boiled again with alkali—for explanation refer to Chapter IV.—but a few minutes' boiling will in this case suffice to show that oats contain a fair but by no means excessive proportion of fibre.

Ash. Put a gram or two of oatmeal in a crucible and place on a porcelain triangle over a flame. Note that the oatmeal burns away and leaves a small quantity of almost white ash. Disolve this in nitric acid and proceed to test it for lime and phosphate as in Chapter VIII. page 43. Note that oats contain a fair proportion of ash which is rich in both phosphate and lime.

Composition of Oats. To summarise, the above experiments have shown that oats contain a very large proportion of carbohydrates in the form of starch, and fair proportions of protein, oil, fibre, and ash, which latter supplies both lime and phosphates. These are all the necessary constituents of a good diet. As a fact oats form a very well balanced food, and this is no doubt the reason of their popularity, and explains the fact that about three million tons of oats are grown annually in the United Kingdom, which together with nearly a million tons imported from abroad, are

consumed annually by the live stock of the country. Among the concentrated foods, oats form by far the largest item on the bill of fare of the nation's animal population.

A similar set of experiments with the other cereals will prove that though they all show a sort of family likeness to oats, none of them is nearly so well balanced.

Composition of Wheat.

Wheat is much richer in starch, and poorer in oil and ash, and it contains so little fibre that it is apt to become objectionably pasty during mastication unless mixed with a large proportion of some other feeding stuff. Wheat is therefore not popular as a feeding stuff except for poultry Sound wheat is almost invariably sold to the miller; the small and damaged grains removed in screening or winnowing, called tail wheat, being commonly fed to poultry, though sometimes ground for pigs or crushed for other animals.

Composition of Barley.

Barley is similar to wheat in composition, with the exception that it is poorer in protein and richer in fibre. Its higher content of fibre makes it much more pleasant to masticate, and therefore more palatable, and it is a popular feeding stuff, especially for pigs, which when fed on barley are said to yield excellent quality pork and bacon with firm but tender fat. It is also used for sheep, and parched barley is the staple food for horses in countries whose climate is too hot to grow oats. Being poorer in protein and richer in starch than oats it is not so well balanced, and is therefore usually fed in conjunction with some more nitrogenous feeding stuff such as beans, peas, or oilseed cake of some kind. The annual production of barley in the United Kingdom is well over a million tons. Rather less than that amount is imported, so that the annual consumption is approximately two million tons. The brewing industry consumes rather less than a million tons, live stock about the same amount, the remainder being sown as seed, and a very small fraction used for the preparation of such human foods as pearl barley.

Rye.

Rye forms so small an item in the bill of fare of the country's live stock that it is scarcely deserving of mention. In composition it is almost identical with wheat. It is little used as a feeding stuff, since most of it is sown again in order to produce green fodder.

Composition of Maize.

Maize is a very ill-balanced feeding stuff, being exceedingly rich in starch and poor in protein, fibre, and ash. It contains a fair proportion of oil. In consistency it is very hard and flinty, and unless finely ground or cooked is not completely digested by some animals.

This does not mean that it is not a useful and valuable feeding stuff. All that it implies is that it must be used in conjunction with such other feeding stuffs as will correct its deficiencies.

Maize is grown in this country as green fodder, but cannot be depended upon to ripen grain in an ordinary British summer. It is very largely grown in the United States, where the annual production reaches the almost incredible figure of 70 to 80 million tons. Large quantities are also grown in South America and South Africa.

About two million tons are imported annually into the United Kingdom from these countries, over one and a half million tons of which are consumed by animals. Horses, cattle, sheep, and pigs all take part in this consumption, but most of it probably goes to pigs, in spite of the fact that maize fed pigs are said to yield poor quality bacon and pork with tough, soft, greasy fat.

Composition of Rice.

Rice is cultivated only in hot countries and is not grown at all in the United Kingdom. The quantity imported is relatively small and most of it is used for human food. The small amount fed to animals consists of two grades: ground or crushed inferior rice and what is commonly called rice meal. The former is even richer in starch than maize, and at the same time poor in proteins and oil. It is an ill-balanced feeding

stuff, which should only be used in conjunction with other feeding stuffs which are capable of making up its deficiencies.

Rice meal is a very different product. It consists of the finely ground outer layers of the rice grain which are separated in the process of preparation for human food—hulling and polishing as the process is called. The protein and oil of the grain collects in these outer layers. Consequently rice meal is comparatively rich in these constituents and contains correspondingly less starch. It is a much better balanced feeding stuff and gives good results as a constituent of the diet of fattening animals. On account of its rather sticky consistency it is chiefly used by manufacturers of mixed feeding cakes because it helps to bind together the other constituents.

Millers' Offals.

Millers' offals are the various products separated from wheat in the process of milling. Broadly speaking they consist of the germ and the outer layers of the grain, and as the protein, oil, and ash of the grain are chiefly deposited in these structures, the offals contain a greater proportion of these valuable ingredients and are consequently better balanced feeding stuffs than the whole grain would be

Before the war four grades of offals were on the market, namely, fine middlings, which were not widely different in composition from flour, but contained rather more protein, oil, and ash; coarse middlings, containing still more protein, oil, fibre, and ash, and appreciably less starch; pollards, which were still richer in ash and fibre but rather poorer in protein, oil, and starch than coarse middlings; and finally bran, which contained as much as ten per cent. of fibre, and five per cent. of ash, and correspondingly less of the other constituents.

During the war the milling industry went through a long period of government control which has left as an apparently permanent effect a different and much simpler method of grading offals. Fine middlings and pollards, as separate grades, have almost disappeared from the market, and at the

present time only two grades of offals are being sold, coarse middlings and bran.

Coarse Middlings.

Coarse middlings, the finer of these grades, is sold under a great variety of names, such as supers, sharps, toppings, thirds, and so on. As met with to-day it includes the coarser portions of pre-war fine middlings, the finer portions of pre-war pollards, and, as its name implies, all the pre-war coarse middlings. It is a most useful and well-balanced feeding stuff approximating somewhat in composition to oats, though it is rather richer in protein and poorer in fibre. Its main use is for feeding pigs, for which purpose it is excellent. It is also used in some districts for milch cattle kept under urban conditions.

Bran.

Bran is sold in two grades, broad bran and ordinary bran. There is no appreciable difference in composition between the two. Broad bran is, however, more flakey and freer from floury matter than ordinary bran and on this account realises a higher price, which does not appear to be justified by higher food value.

Bran, on account of its comparatively high content of fibre, is not a very digestible food. Its actual food value is only about two-thirds that of coarse middlings. Nevertheless, bran is a valuable feeding stuff rather because of its laxative properties than of its high food value. It is too fibrous for pigs, but is largely used for horses and cattle.

Millers' offals constitute one of the larger items in the bill of fare of the country's live stock. The annual consumption in the United Kingdom is in the neighbourhood of two million tons, more than half of which at the present time is coarse middlings.

Brewers' Grains.

Brewers' grains are used either wet or dry. Wet grains consist of the residue of the malt left when the wort is separated after mashing. They contain nearly 70 per cent. of water, which makes them very prone to ferment or putrefy. Their use is therefore almost exclusively confined to the feeding of animals,

usually dairy cows, kept quite near the brewery, so that they can be consumed while fresh. Even then care must be taken to keep the mangers clean or trouble may ensue. Dried grains consist of the above wet grains which have been artificially dried until they contain only about 10 per cent. of water. They are somewhat similar in composition and food value to bran but do not possess its laxative properties.

Malt culms are the dried sprouts separated from germinated barley after drying and before grinding in the process of malting. They are somewhat similar to dried grains in composition and food value.

CHAPTER XIII.

THE LEGUMINOUS GRAINS.

Beans and peas are the only leguminous grains grown in this country for feeding animals. Although they belong to different genera, and like different kinds of soil, they are very similar in composition.

The following experiments should be performed with ground peas or beans to demonstrate the main facts.

Heat a little of the meal mixed with soda lime in a test-tube. Test the evolved gas with a piece of moistened red litmus paper, and note the copious evolution of ammonia. This indicates a high percentage of protein; in fact, peas and beans contain more than twice as much protein as the cereal grains do.

Testing for Protein.

Shake some of the meal with ether. Filter and evaporate away the ether from the filtrate as before, Note the very small oily residue, showing a very low content of oil.

Fat.

Boil a little meal with water. Note that it swells up, suggesting the presence of much starch. Cool, and add iodine solution. A deep blue colour shows an abundance of starch.

Starch.

Boil about a gram of meal with acid as before (p. 66), and note that a fair proportion of fibre remains undissolved.

Fibre.

Burn some meal in a crucible. Note that a considerable amount of ash remains. Test it for lime and phosphates as before (p. 43), and note that it is rich in both these constituents.

Ash.

Composition of Beans and Peas.

Beans and peas are, therefore, rich in protein and ash, they contain a fair proportion of carbohydrates in the form of starch, and they are poor in oil. They are valuable feeding stuffs, and are commonly used to make up in the diet the deficiency of protein in other feeding stuffs. For instance, when using maize for horses, crushed beans are commonly included in the ration.

Beans are also used for the same purpose in feeding pigs, and are reputed to produce excellent quality flesh and fat. Finely ground bean meal is a common ingredient of what is known as milk substitute for calves. Bean meal is also regarded as an excellent addition to the ration of fattening cattle, more especially in the last stages of fattening for market.

Peas are a favourite addition to the diet of pigs, and are also fed successfully to sheep when folded on roots in the winter.

Both beans and peas are somewhat difficult of digestion. They are generally used either coarsely crushed or finely ground, seldom whole. In using them it should never be forgotten that they are rich in protein. Consequently they should never form more than a small proportion of the diet. Their real value is to make up for the deficiency of protein in other feeding stuffs.

Foreign Peas and Beans.

Several varieties of foreign peas come on to the home markets. They have much the same food value as home-grown peas, and are usually a safe and inexpensive food.

Testing for Prussic Acid.

There are also a great variety of foreign beans which are imported from China, Burmah, and other eastern countries. Some of these are as good as home-grown beans, whilst others are frequently poisonous. Unfortunately; few people are able to identify the poisonous varieties by inspection. An analyst can, however, readily decide if they are poisonous by the

following test. The poisonous constituent of foreign beans is a substance known as a glucoside, because it is a chemical compound of sugar (glucose), prussic acid, and usually some other constituent. The glucoside itself is bitter but harmless, but when kept warm and moist, for instance, in the rumen or paunch of an animal, it is split up by an enzyme which occurs in the same seeds, into its constituents, among which is prussic acid, which latter is, as is well known, exceedingly poisonous. The test is carried out thus: Some of the suspected beans are ground to powder, moistened with water in a loosely-corked flask, and kept for some hours in a warm place, usually an incubator at the temperature of the animal body—about 40° C. During this treatment the enzyme splits the glucoside and sets free the prussic acid. More water is then added, a condenser is connected to the flask, and some of the water is distilled over. To this are added a few drops each of ferrous sulphate, ferric chloride, and sodium hydrate solutions. Hydrochloric acid is then added, when if the beans were poisonous a blue precipitate of Prussian blue will be seen. Very frequently it is necessary to pour the liquid through a filter, when the Prussian blue will be left as a blue stain on the filter paper.

Beans which give this test are not safe for use as a feeding stuff.

Gram.

Gram is a small leguminous grain which is sometimes met with on home markets. It is something like vetch seed in appearance, and is grown in large quantities in India and other eastern countries, where it is commonly used to make up the deficiency of protein in barley as a ration for horses. It is similar in composition to beans and peas, and may be used for the same purposes.

Oil Seeds.

All the above leguminous seeds are poor in oil, of which constituent they contain only from 1 to 1½ per cent. Two other leguminous seeds which are imported into this country, namely, soya beans and ground

or earth nuts, are exceedingly rich in oil. Soya beans contain about 17 or 18 per cent. of oil, and ground nuts as much as 45 per cent. Both are also exceedingly rich in protein and correspondingly poor in carbohydrates, so that they contrast sharply with all the feeding stuffs whose composition we have discussed.

Soya Beans.

Soya beans are grown chiefly in Japan and Manchuria, where they are one of the staple crops. They do not appear on the home feeding stuff markets in their natural state, but are bought wholesale by the oil-crushing mills, where their oil is separated for the manufacture of margarine or soap. The residue left after crushing out the oil is sold on the markets as soya bean cake.

Soya Bean Cake.

Soya bean cake is a light-coloured cake which is usually very hard and tough. It is exceedingly rich in protein, of which it contains over 40 per cent Its other constituents are about 7 per cent. of oil, fair proportions of fibre and ash, and comparatively little carbohydrates. It is said to exert a distinctly laxative effect on the digestive organs. For this reason, and because of its exceeding richness in protein, it should never be used in large quantities. A full-grown ox requires only about $1\frac{3}{4}$ lb. of protein per day. The normal ration of $\frac{3}{4}$ cwt. of roots and a stone of hay or straw supplies about 1 lb. of protein, leaving only $\frac{3}{4}$ lb. to be supplied by the concentrated food. Two pounds of soya bean cake would supply rather more than this amount, and more than this should not be used. It would be wiser to use only 1 lb. as an adjunct to some other concentrated feeding stuff.

Ground Nuts.

Ground or earth nuts are grown in many hot countries, notably in the various States on the East and West Coasts of Africa. As in the case of soya beans, they are seldom bought in their natural state in this country, except by children under the name of pea nuts or monkey nuts. Practically the whole import is crushed

for oil, with or without removal of the husks. If the husks are completely removed the resulting cake is known as decorticated ground nut cake. The cake resulting from crushing without removal of the husks is known as undecorticated ground nut cake. An intermediate product, from which part of the husk has been separated, is called semi-decorticated ground nut cake.

Decorticated ground nut cake is a valuable and safe feeding stuff, very similar in composition to soya bean cake, but without its laxative properties. It should, however, be used in small quantities, because of its very high content of protein. Used in excess of an animal's requirements protein is of doubtful advantage. It is not so valuable for producing either work or fat as is carbohydrate, than which it is much more expensive. Further, it has to be excreted from the body through the kidneys on which it throws much extra work, sometimes with disastrous results.

Undecorticated ground nut cake resembles undecorticated cotton cake in composition, containing 22 to 23 per cent. of fibre. It contains, however, considerably more protein and oil than does undecorticated cotton cake, and has a distinctly higher nutritive value. It does not, however, possess the astringent properties which make cotton cake so useful for cows on lush grass in the spring and autumn, and for bullocks when they first begin root feeding in the yards.

Oil Cakes.

As this is the first occasion on which we have mentioned oil seed cakes, it seems opportune to give a short description of the process by which such feeding stuffs are manufactured.

Oil seed cakes are essentially by-products. Seeds, such as soya beans and ground nuts, which have been described above, and many others, such as linseed, cotton seed, rape seed, palm kernels, and coconuts are valuable in the first place for the oil which they contain. Oil is required in very large quantities for a variety of purposes. Soap is made from oil. Glycerine, which is used in the manufacture of

explosives, is a by-product in the manufacture of soap. By a comparatively modern process liquid vegetable oils are made to combine with hydrogen, which converts them into semi-solid fats suitable for making margarine.

Manufacture.

The usual process of obtaining the oils required for these purposes is to grind the seeds to a coarse powder, which is then packed in strong bags, which retain the solid matter but allow the oil to escape. These bags are then placed between pairs of hinged boards, which are corrugated and engraved with the name of the maker and of the brand of cake. These pairs of hinged boards, each enclosing a bag of seed, are then piled up inside a hydraulic press. Enormous pressure is then applied, which squeezes out the oil and makes the solids stick together into a cake, on which is impressed the corrugations of the boards, the name of the maker, and of the brand of the cake. When the pressure is released the cakes are withdrawn from their bags, and packed in sacks for distribution to buyers.

By this method of manufacture it is not possible to squeeze out the whole of the oil. From 5 to 10 per cent. of oil is still left in the cake, and, as oil is a very valuable food, this residue of oil greatly increases the nutritive value of the cake.

Extraction Process.

An alternative method of extracting oil from seeds has come into use in recent years, and is likely to be extended if oil becomes more expensive. It is carried out as follows:—The coarsely-ground seed is mixed with benzene, petrol, or some other solvent. This dissolves the oil, but does not dissolve the other constituents. The solvent containing the oil is then separated by filtering under pressure. The solvent is then separated from the oil by distilling it off, so that it is recovered and can be used again. The insoluble residue of the seed, from which the oil has been thus extracted, is then warmed to remove the last traces of solvent, and a dry powder or meal

results, which is, or should be, sold as a feeding stuff under the name of extracted meal.

"Extracted" Meals.

This method of extraction yields more oil than the crushing method, but the residue is an extracted meal, not a cake. The extracted meal usually contains not more than 1 per cent. of oil, and is correspondingly lower in nutritive value than the cake, which, as mentioned above, usually contains from 5 to 10 per cent. of oil.

It is instructive to shake with ether equal quantities of ground up cake and extracted meal made from the same seed, filtering, evaporating away the ether, and comparing the amounts of oil left in the porcelain dishes from which the ether was evaporated.

CHAPTER XIV.

ANALYSIS OF LINSEED CAKE.

Composition of Home-grown Fodders.

Looking back through the preceding chapters, which have been devoted chiefly to a description of the composition and properties of home-grown feeding stuffs, one cannot help arriving at the general conclusion that the fodders grown in this country supply abundance of carbohydrates, such as starch, sugar, and fibre, but that on the whole they are deficient in the two very important constituents, proteins and oils or fats.

There are, of course, certain notable exceptions. Good hay, oats, and millers' offals are fairly well balanced feeding stuffs. Beans and peas contain abundance of protein, but almost no fat. These, however, are not sufficient in amount to balance the deficiencies in protein and fat of the large quantities of straw, roots, and barley grown in the country and the 1½ million tons of imported maize.

Looking, therefore, at the bill of fare of the country's animal population as a whole, it is evident that what is wanted to balance the total ration of our live stock is more protein and more fat. This fact sufficiently explains the popularity of oil-seed cakes among live stock owners, for these cakes are characteristically rich in proteins and fats, and correspondingly poor in other constituents, notably carbohydrates. It is fortunate for the live stock industry that the demand for oil for various manufacturing purposes produces by-products which meet the requirements of the animals of the country so exactly as do oil seed cakes and other oil-seed residues.

Importance of Analysis.

These oil-seed cakes and residues vary very widely in composition and purity. Consequently they should always be bought on a guaranteed analysis, stating the name of the seed from *which they are made, the chemical composition*, and the purity.

In order that the meaning of such a guarantee should be fully understood it is desirable that a complete examination of at least one such feeding stuff should be carried out. We will, therefore, make a complete examination of a delivery of linseed cake bought on a guarantee that it is pure linseed cake containing 28 per cent. of protein and 8 per cent. of oil.

Sampling.

In making such an examination the first step is to obtain a sample which fairly represents the bulk of the delivery. For this purpose we take one cake out of every tenth bag, or, if the delivery is large, we may take a cake from every twentieth bag, or every fortieth bag, so that we have ten or twenty sample cakes.

Now it is not satisfactory to break off a bit from the end of each sample cake, for, since the oil when being squeezed out drips from the ends and sides of the cakes, these ends and sides are likely to be somewhat richer in oil than the central parts. To obviate this difficulty break each sample cake across the middle by taking one end in each hand and bending the cake against the edge of a bench or table. Next break off by the same method a strip, say 3 inches wide, from one of the broken ends, and again break this across its middle. This will give a small piece of cake about 3 inches wide by 4 to 5 inches long including the proper proportion of middle and outside. Take such a strip from each of the sample cakes and put the whole lot through the cake crusher, which should be set to crush them as finely as possible, If necessary put them through several times so that they are all finely broken and well mixed.

If the examination is to be made solely for your own information all that remains to be done is to put a pound or two of this finely divided material into a wide-mouthed bottle or tin which can be tightly closed to prevent evaporation or absorption of water. If, however, you contemplate legal proceedings as a result of the examination, the whole of the sampling operations should be carried out in the presence of an accredited witness, and three bottles or tins should be filled with the finely divided material, each being labelled, dated, sealed, and signed by the witness. One should be used for your own or your analyst's examination, *the second should be sent to the agent from whom the cake* was purchased, and the third kept for examination by a referee in case of dispute.

Having obtained a representative sample in this way, the examination is conducted as follows:—

Looking for Impurities.

The broken surfaces of several small pieces of the cake are looked over very carefully, first with the naked eye *and then with a hand lens. In this way it* should be possible to decide if the cake is linseed cake free from impurities. Pure linseed cake should have thin light red husks packed between the yellowish grey powdery material from the inside of the seeds. The impurities to look for are bits of straw or other fibrous materials, dark coloured thick, often shiny, husks of such seeds as rape, polygonum, corn cockle, or other weeds which have been left in the linseed by inadequate screening, or, very occasionally, castor oil seed husks or other materials added to the cake by way of adulteration. A bit of the cake should also be chewed, which may disclose the presence of acrid impurities, such as rape or mustard seed, or sandy gritty material not completely removed when the seed was screened.

The rest of the sample should now be ground to a fine powder in a small mill.

Genuineness.

From 10 to 20 gm. of the powder is now put into a beaker, and about 100 c.c. of boiling water poured on to it. It is now thoroughly stirred with a glass rod, covered with a clock glass, and left to stand.

Linseed contains a peculiar carbohydrate, known as linseed mucilage, which swells up in hot water, making a thick translucent solution, through which the reddish husks settle to the bottom. Genuine linseed cake treated as above gives three layers—the husks at the bottom, the thick translucent solution at the top, and between these a whitish layer containing much granular or powdery material.

Remove the clock glass and note the smell. Linseed has quite a characteristic odour, which should be free from the acrid smell of mustard or other cruciferous seeds. Pour off some of the two top layers into a test-tube, boil it, cool, and add iodine solution. There should be no blue colour, as linseed contains no starch. A blue colour shows that the cake is contaminated with starchy seeds.

Now stir the contents of the beaker again with a round-ended glass rod, feeling for grit, which, if present, will have settled to the bottom of the beaker. In this way it is possible to judge of the amount of sandy matter left in the cake by inefficient cleaning of the seed before crushing.

While stirring watch the sides of the beaker to see if any husks which look unlike linseed are present. If you see anything suspicious, pick it out, transfer it to a glass slide, and examine it under a microscope, identifying it by comparison with the drawings in *Microscopic Analysis of Cattle Foods*, by T. N. Morris (Cambridge University Press, 2s.).

By these preliminary tests it is possible to form a good opinion as to the purity and genuineness of the sample, and the quantitative analysis can now be undertaken.

Estimation of Water.

Weigh a porcelain crucible, after heating it and allowing it to cool in a desiccator. Put into it 3 or 4 grams of the powdered cake, and weigh again accurately. Place the crucible and its contents in the drying oven, and leave it there for some hours. Cool in a desiccator and weigh. Replace in the oven, and repeat the cooling and weighing until no appreciable change in weight occurs during one hour in the oven, which shows that all the water has evaporated. Calculate percentage of water thus:—

Weight of cake + crucible	12·988 gm.
Weight of crucible	9·553 gm.
Weight of cake taken	3·435 gm.
Weight of crucible + cake after drying ...	12·714 gm.
Weight of crucible + cake before drying...	12·988 gm.
Weight of water in cake	·274 gm.

$$\text{Percentage of water } \frac{\cdot274 \times 100}{3\cdot435} = 8\cdot0 \text{ per cent.}$$

Estimation of Ash.

Stand the crucible on a pipe-clay triangle supported on a tripod, and heat it with a flame placed rather to one side, so that the crucible is not completely enveloped in the flame, which would prevent access of the oxygen required to make the cake burn.

Note that the cake takes fire, blackens, and burns away, leaving a grey ash. If necessary, hasten the process by stirring carefully with a thin wire. When no more black specks remain, turn out the flame, and remove the crucible to the desiccator, weighing it when cold.

Calculate percentage of ash thus:—

Weight of crucible + ash	9·822 gm.
Weight of crucible alone	9·533 gm.
Weight of ash	·269 gm.

$$\text{Percentage of ash } \frac{\cdot269 \times 100}{3\cdot435} = 7\cdot8 \text{ per cent.}$$

This is rather a high percentage of ash, and when this is the case the cause is usually the presence of sandy impurities not completely removed when the seed was screened. Pour very carefully into the crucible a few drops of strong hydrochloric acid, which will dissolve the constituents of the real ash of the linseed, but will not dissolve sand. Wash the contents of the crucible into a small beaker with hot water, boil for a moment, and feel for grit on the bottom of the beaker with a glass rod.

Testing for Sand.

To find the percentage of this sand or grit, fold a small filter paper and fit it carefully into a funnel. Pour the contents of the beaker down a glass rod on to the filter, washing all the grit on to the filter with hot water. Wash several times with hot water. Dry the paper by putting the funnel into a drying oven. Meanwhile heat, cool, and weigh a crucible. When the filter paper is dry, take it out of the funnel, and fold it up so that it will go into the crucible. Take great care not to lose any of the sandy particles. Burn the paper in the crucible just as you burnt the linseed. Cool and weigh. Calculate thus:—

Estimation of Sand.

Weight of crucible + sand	9·602
Weight of crucible alone	9·552
Weight of sand	·050

$$\text{Percentage of sand } \frac{\cdot 050 \times 100}{3\cdot 435} = 1\cdot 5 \text{ per cent.}$$

The total ash amounting to 7·8 per cent. evidently contains 1·5 per cent. of sandy impurities, so that the real ash of the linseed amounts only to 7·8 — 1·5 per cent., or 6·3 per cent., which is much more like the correct figure.

The next constituent to estimate is the protein. To make this estimation we assume, firstly, that all the nitrogen in the cake exists in the form of protein, and, secondly, that the protein contains 16 per cent. of nitrogen. The first assumption is

Estimation of Protein.

practically true for a ripe seed, though it would be quite unjustified in the case of unripe succulent fodders like grass or roots. The second assumption is also probably quite near the truth, and is good enough for our purpose, because all analysts have agreed to work on the same assumption so that they may all obtain comparable results.

Working on these two assumptions, all we have to do is to find the percentage of nitrogen and multiply it by 100 ÷ 16, which is 6·25.

Estimation of Nitrogen.

We will use the method known as Kjeldahl's method, and proceed thus: weigh a small clean dry test-tube. Put into it about 1 gm. of the powdered cake, adding a little more or shaking a little out until the quantity left in is approximately 1 gm. Weigh again accurately. Hold the tube upright, and invert over it a long-necked hard glass flask. Now turn the flask and tube upside down, so that the cake falls into the flask without sticking to the neck of the flask. Tap the tube against the neck of the flask so as to shake out the cake as completely as possible. Weigh the tube again accurately.

Weight of tube + cake...	4·783 gm.
Weight of tube	3·751 gm.
Weight of cake	1·032 gm.

Now measure out in a small measuring cylinder 10 c.c. of pure strong sulphuric acid, and pour it into the flask, swirling it round so that it wets the whole of the powdered cake. Place the flask on a stand in the draught chamber, and heat it slowly with a very small flame. The sulphuric acid at once chars the cake by taking water from the organic compounds of which it is composed, thus setting free carbon. As the mixture gets hot this carbon is oxidised to carbon dioxide gas by the sulphuric acid, which is itself reduced to sulphur dioxide gas. Much gas is, therefore, given off, and it is necessary to watch the flask and adjust the flame, or the mixture may froth so much that some of it is lost. During

the process of setting free and oxidising the carbon the sulphuric acid also separates the nitrogen of the cake. This nitrogen remains in combination with hydrogen in the form of ammonia, which combines with the sulphuric acid, forming ammonium sulphate. As soon as the frothing ceases, add to the mixture, which is now black from the presence of carbon, about 5 gm. of powdered ignited potassium sulphate. This addition raises the boiling point of the sulphuric acid, and at the same time makes up for the fact that in the chemical actions mentioned above some of the acid has been reduced to sulphur dioxide gas which has been lost, and the rest has been diluted by the water abstracted from the cake.

The addition will cause a second frothing. As soon as this has subsided, turn up the flame and heat the mixture until all the carbon has been oxidised, as shown by the complete disappearance of the dark colour. All the nitrogen has now been separated from the other constituents of the cake, and is dissolved in the clear colourless liquid in the flask in the form of ammonium sulphate. Turn out the flame and let the flask cool.

Meantime prepare a distilling apparatus, consisting of a large round-bottomed flask fitted with a rubber cork, through which pass a bulb with a stop cock, and a splash trap connected with a condenser and receiver. Measure into the receiver, by means of a pipette, 10 c.c. of semi-normal hydrochloric acid, and moisten the glass beads in the exit tube of the receiver with 3 drops of methyl orange indicator.

Disconnect the distilling flask, and wash into it with distilled water the clear colourless liquid which resulted from boiling the cake with sulphuric acid, rinsing the flask several times with water, so that everything it contains is transferred to the distilling flask. Drop into the distilling flask a piece of pumice stone wrapped round with copper wire to make it sink. The object of this is to make the liquid boil steadily.

Connect the distilling flask to the condenser, twisting the

cork in tightly, and measure into the bulb enough very strong solution of sodium hydrate to neutralise all the sulphuric acid, and make the liquid in the flask strongly alkaline. If the sodium hydrate solution is 50 per cent., 50 c.c. will be sufficient. Shake the flask gently so as to mix the contents, put a flame under it, and distil off about 100 c.c., adjusting the flame so as to avoid frothing, and so that the pink colour of the indicator in the exit tube of the receiver does not change to yellow. The sodium hydrate decomposes the ammonium sulphate, setting free ammonia, which passes over into the receiver with the steam, and neutralises some of the standard hydrochloric acid.

When about 100 c.c. has distilled over it will have carried with it all the ammonia. Turn out the flame, and at once disconnect the distilling flask. Remove the receiver, washing the end of the distilling tube and the exit tube. The liquid in the receiver should be pink on account of the presence of the methyl orange indicator washed into it from the beads in the exit tube.

Fill a burette with semi-normal solution of sodium hydrate, and adjust the level of the solution to 0. Place the receiver under the burette, and run in the alkali a drop at a time, shaking between each addition, until the pink colour changes to orange. Read the burette at this point. Suppose it is 2·9 c.c. Run in one more drop, and note that the colour changes to light yellow, showing that the liquid is now alkaline. Neutrality was, therefore, reached by the addition of 2·9 c.c. of semi-normal alkali.

If the 10 c.c. of semi-normal acid put in the receiver had been titrated at once with semi-normal alkali it would have required 10 c.c. But so much of it had been neutralised by the ammonia from the cake that it required only 2·9 c.c. This ammonia must, therefore, have neutralised the difference between 10 c.c. and 2·9 c.c., which is 7·1 c.c,

The ammonia formed from the protein of 1·032 gm. of the sample of cake was, therefore, enough to neutralise 7·1 c.c. of

semi-normal hydrochloric acid, and it is easy to calculate its amount, for 1 c.c. of semi-normal acid is exactly neutralised by that amount of ammonia which contains ·007 gm. of nitrogen. It follows, therefore, that 1·032 gm. of cake contained $\cdot 007 \times 7\cdot 1 = \cdot 0497$ gm. nitrogen, which is equivalent to

$$\frac{\cdot 0497 \times 100}{1\cdot 032} = 4\cdot 7 \text{ per cent.}$$

Calculation of Nitrogen as Protein.

Since all the nitrogen in the cake is assumed to exist as protein containing 16 per cent. of nitrogen, this percentage of nitrogen corresponds to $4\cdot 7 \times \frac{100}{16} = 4\cdot 7 \times 6\cdot 25 = 29\cdot 4$ per cent. of protein.

The calculation may be summarised thus:—

Weight of cake taken, 1·032 gm.

Volume of N/2 acid in receiver	10 c.c.
Volume of N/2 alkali required to neutralise	2·9 c.c.
Volume of N/2 acid neutralised by NH_3...	7·1 c.c.

Weight of N in cake $\cdot 007 \times 7\cdot 1 = \cdot 0497$ gm. N.

$$\text{Percentage of N in cake} = \frac{\cdot 0497 \times 100}{1\cdot 032} = 4\cdot 7 \text{ per cent. N}$$

Percentage protein in cake $4\cdot 7 \times 6\cdot 25 = 29\cdot 4$ per cent. protein.

CHAPTER XV.

ANALYSIS OF LINSEED CAKE—*continued.*

The sale of feeding stuffs in the United Kingdom is regulated by an Act of Parliament known as the Feeding Stuffs and Fertilisers Act which prescribes that every delivery of more than one cwt. of a feeding stuff or fertiliser must be accompanied by an invoice on which is stated the percentages of nitrogen, phosphoric acid, and potash in the case of fertilisers, and of protein and oil in the case of feeding stuffs. We have already estimated the percentage of protein and our next step is to estimate the percentage of oil.

Estimation of Oil.

This is carried out by taking advantage of the fact that the organic solvent ether dissolves oil quite readily but does not dissolve any of the other constituents of feeding stuffs. The procedure is as follows: cut an oblong sheet of filter paper about eight inches long and five inches wide. Roll it round a test-tube so as to make a hollow cylinder five inches long, and close one end by bending it over. Weigh it accurately. Now put into it about five gm. of the powered cake and weigh again—

Weight of paper cylinder + cake	7·585 gm.
Weight of paper cylinder alone	2·212 gm.
Weight of cake	5·373 gm.

Fold over the open end of the paper so as to enclose the weighed quantity of cake in a small paper case. Push this into the wide test-tube of a Soxhlet fat extraction apparatus.

Meantime select a wide mouthed flask to fit the cork on the extractor, dry it in the water-oven, cool it in a desiccator, and weigh it accurately. Push the cork of the extractor firmly into the neck of the weighed flask, and connect the

upper end of the extractor to a condenser. Pour ether into the upper end of the condenser until it fills the tube of the extractor and syphons over into the weighed flask. Add more ether until it nearly syphons over a second time. Turn on a slow stream of cold water through the condenser, and fix up the whole apparatus so that the weighed flask is partly immersed in a water bath. Adjust the flame under the water bath so as to warm the bath enough to keep the ether boiling.

The vapour of the ether rises through the side tube of the extractor into the condenser, where it is condensed into liquid and drops back on to the little parcel of cake, rising in the tube until it reaches the level of the top of the syphon. As soon as it reaches this level the ether syphons into the weighed flask carrying with it the oil which it has dissolved out of the cake. The water bath must be kept warm enough to boil the ether until this process has been automatically repeated at least a dozen times, which should take about two hours. By this time the ether will have carried all the oil into the weighed flask, and the filter paper in which the cake was enclosed will have kept back all the other constituents which the ether does not dissolve.

Now turn out the flame, disconnect the weighed flask, reverse the condenser, connect the flask to the other end, and distil off the ether. Again disconnect the weighed flask and place it in the water-oven to evaporate the last traces of ether and any moisture which the ether may have contained or dissolved out of the cake. After drying for about two hours, cool the flask in the desiccator and weigh it accurately. Calculate thus:

Weight of flask + oil	31·876
Weight of flask ...	31·380
Weight of oil ...	·496

$$\text{Percentage of oil } \frac{\cdot 496 \times 100}{5\cdot 373} = 9\cdot 2 \text{ per cent.}$$

It should be noted that this method, like the method used for estimating protein, depends on the assumption that ether dissolves all the oil out of the cake and nothing except the oil. It will dissolve all the oil of the cake if the cake is finely ground, and in the case of linseed cake it dissolves very little indeed except oil, so that in this case the results are sufficiently accurate. In the case of dried green fodders such as hay it is not so easy to ensure fine grinding, and the ether dissolves chlorophyll and certain waxy materials as well as oil, so that the method is less accurate.

Estimation of Fibre.

Although we have now estimated the two constituents prescribed by the Feeding Stuffs and Fertilisers Act, it is usual also to estimate the percentage of what analysts call fibre, and this for two reasons. Firstly, because the percentage of fibre gives valuable information in classifying feeding stuffs, and secondly, because until we have estimated the fibre we cannot calculate the percentage of carbohydrates. Fibre as we know is impure cellulose, and is characteristically insoluble in the usual solvents such as acids and alkalis which dissolve all the other constituents. There is no absolute method of estimating the percentage of fibre, but analysts have agreed upon a method which gives satisfactory results and does not lead to confusion so long as all analysts proceed in exactly the same way. Such a method is called a conventional method, and its success depends upon the exact observance of the details of working, which are as follows:—Cut two small squares of glazed paper, about 3 inches square, and place one on each pan of the balance. Snip small bits off the heavier until the two exactly counterpoise each other. Place a 2 gm. weight on the paper on the right-hand pan and carefully shake powdered cake on to the paper on the left-hand pan until the two pans swing level. Pour the 2 gm. of powdered cake weighed out thus into a 300 c.c. beaker, and add 25 c.c. of dilute sulphuric acid containing 10 per cent. of H_2SO_4. Now add 175 c.c. of water. The beaker will now

contain 2 gm. cake and 200 c.c. of solution containing $1\frac{1}{4}$ per cent. of H_2SO_4.

Gum a label on the side of the beaker so that the upper edge of the label is exactly level with the upper surface of the solution. This will mark the height reached by 200 c.c. of liquid. Place the beaker on a wire gauze on a tripod and heat it to boiling by a flame. When it begins to boil adjust the flame to maintain steady boiling without boiling over. Cover the beaker with a clock glass to hinder evaporation, and continue boiling for half-an-hour.

At the end of this time remove the flame and while the beaker cools stretch a piece of fine linen over the expanded neck of a filtering bottle tying it in position with a piece of string. Connect the tube of the flask to the suction pump, wet the linen and set the pump working which will pull down the linen. Now pour the still warm liquid from the beaker on to the concave surface of the linen filter, guiding it down a glass rod so that none is lost by splashing. When the liquid is sucked through, wash out the beaker with hot water several times taking care that all the contents reach the linen filter. Wash the fibrous residue on the filter several times with hot water.

This treatment dissolves all the carbohydrates by converting them into sugar which should be tested for in the contents of the filter flask. It also dissolves some of the protein. When the washing is completed, and the filter has been sucked as dry as possible, disconnect the filter flask from the pump, untie the string, and remove the linen, laying it on a clock glass. Stretch it tightly over the hollow side of the clock glass, and with a spatula or blunt knife, scrape the fibrous material from the linen into the same beaker you used for boiling with acid. Wash the last traces from the linen into the beaker by means of a jet of hot water.

Now add 25 c.c. of 10 per cent. solution of sodium hydrate and fill up to the 200 c.c. mark with hot water. Boil as before for half-an-hour. Filter through linen as before,

washing out the beaker very thoroughly and washing the fibrous material on the filter with hot water several times.

This treatment dissolves the oil by converting it into soap and glycerol and completes the solution of the protein. Thus all the constituents of the cake except the fibre or impure cellulose have now been dissolved, and the insoluble fibre alone remains on the linen filter. Scrape it off as before, transferring it to a porcelain crucible which has been previously heated, cooled, and weighed. Place the crucible in the water oven, cooling and weighing it from time to time until it ceases to lose weight. Calculate thus:—

Weight of crucible + fibre	8·754 gm.
Weight of crucible alone ...	8·571 gm.
Weight of fibre	·183 gm.

One more point before calculating the percentage. It is possible that the fibre weighed above may contain a trace of ash which has not been completely dissolved by the acid and alkali. To decide this, place the crucible containing the fibre on a triangle supported on a tripod. Put a flame under the side of the crucible and burn the fibre away as completely as possible. Fibre burns very readily and it will be completely burnt in a very short time. A very small quantity of ash usually remains. Cool and weigh the crucible. Calculate thus:—

Weight of crucible + ash of fibre	8·574 gm.
Weight of crucible alone	8·571 gm.
Weight of ash of fibre	·003 gm.
Weight of fibre containing ash ...	·183 gm.
Weight of ash	·003 gm.
Weight of fibre less ash	·180 gm.

Percentage of fibre in cake $\frac{\cdot180 \times 100}{2} = 9\cdot0$ per cent.

We can now collect together the results of all our estimations, thus :—

Water	8·0	per cent.
†Ash	7·8	,,
*Protein	29·4	,,
Oil	9·2	,,
Fibre...	9·0	,,
Adding up to	63·4	,,

† Containing sand 1·5 per cent.

* Containing nitrogen 4·7 per cent.

Calculation of Carbohydrates.

One constituent has not been estimated, namely the carbohydrates, and in the present state of our knowledge we have no direct method of estimating them. Presumably, however, they make up the difference between the sum of the percentages of the constituents which we have estimated and 100. At any rate we know of no other constituents, so we are not likely to be far wrong in making the assumption that the carbohydrates make up this difference. This indirect and somewhat unsatisfactory method of estimating the carbohydrates in a feeding stuff is accepted by general agreement amongst analysts though every one hopes that in time a better method may be found.

Nitrogen-Free Extract.

The unsatisfactory nature of the method is implied in the continental name for carbohydrates estimated in this way—they are called "nitrogen-free extract"—which means soluble materials other than proteins, and is certainly a more justifiable name to use under the circumstances.

Final Result.

The complete analysis of the sample of linseed cake can now be entered thus :—

Percentage composition of sample of Linseed cake as determined by analysis.

Water	8·0 per cent.
*Protein—often called albuminoids, or flesh formers	29·4 ,,
Oil	9·2 ,,
Carbohydrates, or nitrogen-free extract	36·6 ,,
Fibre	9·0 ,,
†Ash	7·8 ,,
	100·0 per cent.

*Containing nitrogen 4·7 per cent.
†Containing sand ... 1·5 per cent.

The sample is genuine linseed cake free from weed seeds, and of normal average composition except that it contains rather a high percentage of sand. The method described above is that in general use for analysing all kinds of concentrated feeding stuffs such as cakes and meals. When a sample of such a feeding stuff is sent to an analyst for examination this is the method he uses, but there is scope for the exercise of great individual ingenuity and experience in searching the sample for weed seeds and other impurities.

Other Cakes.

A great variety of oil-seed residues appear on the feeding stuff markets, among which may be mentioned coconut cake and meal, a variety of cotton seed products, linseed cake, and several palm kernel products. These will now be briefly described.

Coconut Cake.

Coconut cake is a soft yellowish white crumbly cake with a characteristic smell. It is made by squeezing the oil out of the white fleshy layer, called Copra, which lines the shell of the coconut. It contains about 20 per cent. of protein and about 10 per cent. of oil and is not likely to contain impurities. It is a useful feeding stuff for cattle and pigs, but is not readily

eaten by these animals. Some trouble is usually experienced in getting animals accustomed to it, and for this reason it has not become a popular feeding stuff amongst British live-stock owners.

Various Cotton Cakes.

Cotton seed cake, or to give it its full name, undecorticated cotton seed cake, is made by squeezing the oil out of cotton seed without first removing the husks. It is greenish yellow and contains a very large proportion of black or dark brown husks. There are two chief kinds of cotton seed cake, known as Egyptian and Bombay, corresponding to two kinds of cotton seeds.

Egyptian Cotton Cake.

In Egyptian cotton seeds the cotton fibres or lint are attached in a tuft to one end of the seed, and are therefore almost completely removed in the process of ginning. Cake made from such seeds is therefore fairly free from cotton fibres.

Bombay Cotton Cake.

In Bombay cotton seed the lint is attached more or less all over the seed, and ginning does not succeed in removing it with anything approaching completeness. Consequently cotton fibres are very obvious on the broken surface of Bombay cotton cake.

When first Bombay cake appeared on British markets buyers were afraid that the presence of so much cotton fibre would injure their animals, and were only tempted to buy it by its comparatively low price. Experience, however, has shown that though the cotton fibres are so obvious the actual quantity of them is very small, and they are not dangerous to animals. Bombay cake now sells at practically the same price as Egyptian.

Composition.

Undecorticated cotton cake contains rather over 20 per cent. of protein, about 5 per cent. of oil, and about 22 per cent. of fibre. Its actual nutritive value is low compared with most other cakes, and its very high content of fibre, which is nearly as high as the fibre content of good hay, almost forbids its inclusion amongst

concentrated feeding stuffs. It possesses, however, characteristic astringent properties which make it a most valuable addition to the ration of cattle on lush grass or roots which tend to produce scouring. But for this property its price is generally too high in comparison with its nutritive value to make its purchase as a feeding stuff an economic proposition.

Decorticated Cotton Cake.

Decorticated cotton seed cake, made from cotton seeds which have been decorticated or freed from their husks before being crushed, possesses a much higher nutritive value. It contains about 40 per cent. of protein and 10 per cent. of oil, and removal of the husks has reduced its fibre to from 7 to 8 per cent. It has a bright yellow colour and is rather hard. It is useful for cattle and sheep, but should be used only in small quantities on account of its very high content of protein. It is frequently ground to a fine powder which is sold as decorticated cotton seed meal or yellow meal. Cotton seed products seldom contain impurities as the seeds are kept from contamination by the boll which surrounds them.

Linseed Cake.

Linseed cake is one of the safest and most popular concentrated feeding stuffs on the market. It can be identified by its smell, by its greyish colour, and by the presence of reddish husks. It contains about 30 per cent. of protein, 9 per cent. of oil, and 7 per cent. of fibre, but these figures are liable to considerable variation according to the pressure to which it has been subjected. It is also liable to considerable contamination with dirt and weed seeds. It should therefore always be bought on a guarantee of composition and purity. It is much used for cattle and sheep and sometimes for horses.

Palm Kernel Cake.

Palm kernel cake is a light yellowish white rather soft cake containing small black specks of husk. It results from the crushing of palm nut kernels for oil. It is free from ordinary impurities as the shell in which the kernels grow prevents contamination. It contains about 18 per cent. of protein, about 7 per

cent. of oil, and about 13 per cent. of fibre. It is a valuable feeding stuff for cattle and pigs, and is occasionally used for horses. It has a good reputation for milch cows. It was scarcely known in this country before the war, but during the last two years of the war and in the post-war period its use has been very greatly extended. The chief drawback is that animals do not like it at first, and trouble is often experienced in getting them accustomed to it. It is still on that account not very popular with live stock owners.

Palm Kernel Meal—Extracted.

Palm nut kernel oil is often obtained by extraction with a solvent, in which case the residue is called extracted palm nut kernel meal. This is inferior in nutritive value to palm nut kernel cake as the process of extraction has reduced the oil to 2 per cent. or less, and it is not clear that the nutritive value of the other constituents is unaltered. Buyers of palm kernel meal should make quite sure whether they are buying palm kernel cake meal made by grinding the cake or extracted palm kernel meal made by the extraction process.

CHAPTER XVI.

MISCELLANEOUS FEEDING STUFFS.

Compound Cakes.

All the concentrated feeding stuffs described in the preceding chapters are practically standard articles, each made from one seed only. There are, however, many cakes and meals on the market which have been manufactured for specific purposes by crushing or grinding together two or more materials. These compound feeding stuffs are usually sold as proprietary feeding cakes, dairy cakes, calf meals, pig meals, and so on. They vary greatly in complexity. Some are quite simple, as for instance, the cake known as Soycot, which is made by crushing soya beans and cotton seeds together, so that the astringency of the cotton seed may neutralise the laxative properties of the soya beans. Others contain a great variety of materials which vary from month to month according to price, the only constant properties being the percentages of protein and oil, and the characteristic smell and flavour.

Very great skill is used in their manufacture, as is shown by the fact that such materials as palm kernel cake and meal, which are not readily eaten by animals, form the main ingredients of many popular cakes which all animals eat greedily. The fondness of animals for these compound feeding stuffs is one of the main points in their favour. The use of a feeding stuff which animals eat with relish is conducive to good progress and to economy of labour. Another advantage is that they are usually well designed for the purpose for which they are sold, though some compound feeding stuffs which find their way on to the market offend seriously in this respect.

As compared with such standard feeding stuffs as decorticated cotton cake, ground nut cake, soya bean cake, and even linseed cake, these compound feeding stuffs are low in protein, and can be used safely without risk of the ill effects which sometimes follow the consumption of excessive quantities of protein.

They are, however, in many cases, the refuge of the ignorant. A live stock owner who has taken the trouble to study the feeding of his animals can usually make up a ration with standard articles which will be as satisfactory as, and cheaper than, a ration supplemented by compound feeding stuffs. They are not by-products but specially manufactured articles, and the purchaser must naturally pay for the knowledge and trouble involved in their manufacture. They do not possess any mysterious or marvellous properties which enable the animals fed on them to make more growth or fat or milk than they would make in the ordinary way out of the proteins, fats, and carbohydrates included in the diet. They are usually palatable and fool proof, and it is on these characteristics that their popularity depends.

It would be a great advantage to intelligent purchasers of these compound feeding stuffs if manufacturers would disclose their actual composition in terms of the ingredients of which they are composed. This would make it possible to calculate their content of digestible nutrients and their true nutritive value. Exact knowledge of both these figures is necessary to anyone who wishes to buy in the cheapest market and to work out economic rations.

Examination. Examine the freshly broken surfaces of several samples of compound cakes, both with naked eye and lens, and identify the more obvious constituents. Grind several samples of compound cakes and meals. Boil a little of the ground material in water containing a few drops of sodium hydrate solution. Place some of the insoluble material on a glass slide and examine with the microscope.

Identify the constituents by reference to *Microscopic Analysis of Cattle Foods*, by T. N. Morris.

You will find that these cakes and meals are made for the most part of quite ordinary constituents such as palm kernel meal, coconut meal and so on, with a certain small proportion of spicy flavouring materials such as locust bean pods and fenugreek. In the case of the cakes some kind of binding material is usually present, such as treacle or rice meal.

Treacle.

Besides these proprietary compound feeding stuffs, several feeding stuffs are commonly met with of which treacle or molasses is the predominant constituent. Treacle itself is the residue from the purification of sugar. It contains about 65 per cent. of sugar, 25 per cent. of water, 5 per cent. of ash, and 5 per cent. of various nitrogen compounds which, not being protein, are probably of no feeding value. The nutritive value of treacle is, therefore, confined to the sugar which it contains. Its chief use on the farm is to make chaff more palatable, for which purpose it is diluted with water and spread over the chaff with a watering can. It is somewhat troublesome to make use of it in this manner, and most stock owners only buy it when straw is plentiful and roots are scarce.

Molasses Foods.

Treacle is also a difficult material to ship from the countries where it is produced, for it must be carried in water-tight casks which add to its weight and occupy much space. To avoid this it is sometimes absorbed in the fibrous refuse of the sugar cane. The damp crumbly product, known as molascuit, can be shipped in sacks, and is much more convenient to use than treacle, though it does not serve exactly the same purpose. Other molasses foods consist of treacle absorbed in various fibrous substances so as to yield an easily transported crumbly product. Live stock eat these molasses foods very readily. This and their convenience of handling make them popular. They are, however, rather an expensive form of treacle. The treacle they contain accounts for nearly the whole of their nutritive value. It is

possible, or even probable, that some of the fibrous material which they contain may be digestible, but straw contains 40 per cent. of similar digestible carbohydrates and fibre which, with straw worth on the farm £1 per ton, costs only sixpence per unit or one farthing per lb.

Other Uses of Treacle.

Treacle is also used to improve the palatability of palm kernel meal, a sweetened form of which is usually on the market and is readily eaten by animals. In buying it the guaranteed analysis should be carefully scrutinised so that the purchaser may realise whether it is made from ground cake containing six to seven per cent. of oil, or from extracted meal containing only one to two per cent. The former is, of course, much the more valuable.

Maize Products.

Besides the materials described above, several valuable industrial refuse materials are commonly on offer in the markets. Maize is used in large quantities for making corn flour and in the manufacture of glucose, a form of sugar used in brewing. In the course of manufacture of these materials, considerable quantities of valuable by-products result.

Gluten Meals.

Amongst these may be mentioned maize gluten feed and maize gluten meal. These two products are rich in protein, and both are valuable feeding stuffs for raising the proportion of protein in the ration of all kinds of live-stock. Gluten meal usually contains about 35 per cent of protein, five per cent. of oil, and 45 per cent. of carbohydrates. Gluten feed contains 25 per cent. of protein, three per cent. of oil, and 55 per cent. of carbohydrates. Fibre and ash are low in both—only about two per cent. in each case.

Germ Meal.

Maize germ meal is another maize by-product containing only 13 per cent. of protein and about 13½ per cent. of oil. It differs widely from gluten meal and gluten feed, and is suitable for milch cows and fattening cattle or sheep, but not for pigs.

Testing Maize Products.

Examine examples of gluten feed, gluten meal, and maize germ meal. Note appearance. Heat equal quantities with soda lime and note relative rate of evolution of ammonia. Extract equal quantities with ether, evaporate off the ether, and note relative quantities of oil left in the evaporating dish. Burn a little, and note the small proportion of ash.

Fish Meal.

Fish meal is the product which results from the drying and grinding of the refuse from the fish curing industry. The best quality is called white fish meal, because it is made from the refuse of white fish which contain very little oil. Fish oil is not a desirable constituent of feeding stuffs because of its tendency to produce a fishy taint in the flesh, fat, or milk of animals fed upon it. It also contains in some cases hydrocarbon oils which are of no feeding value.

White fish meal should contain over 50 per cent. of protein, not more than about four per cent. of oil, and only a trace of salt. It also contains over 20 per cent. of ash, which is mainly phosphate of lime, a valuable addition to the diet of many animals. It is a very valuable feeding stuff on account of its very high content of protein and phosphate of lime, but it should only be used in very small quantities or there will be risk of trouble from excessive protein. It is chiefly used in feeding pigs, in which case the daily ration should not exceed from one to eight ounces per head per day according to size.

Such an addition to a pig's ration has a very marked effect on rate of growth, partly because of the protein, partly because of the phosphate of lime. It is commonly stated that the chief value of fish meal lies in its high vitamine content, but this is doubtful, for white fish meal containing little oil is not a rich source of vitamines.

Another reason for not exceeding the ration of fish meal stated above is that with such a ration the risk of tainting the carcase is much reduced. Since fish meal is most valu-

able for producing growth rather than fattening, it is advisable to discontinue its use during the last month or so before slaughter whilst the animals are fattening. This will again reduce the risk of tainting the carcase without hindering the formation of fat.

Oily fish meals made from the refuse of herrings, mackerel, and other oily fish are not suitable for use as feeding stuffs. They may be rich in vitamines, but the risk of tainting milk or carcase is too serious.

Cod Liver Oil.

Cod liver oil is sometimes used to promote growth in young animals, especially calves which are reared on milk substitutes. It is an easily digestible oil of high nutritive value and most samples are rich in vitamines. There is no chemical test for vitamines. The only really reliable test is their effect on animals which have been kept on a vitamine-free diet until growth has ceased. It has been shown, however, that samples of cod liver oil which the animal test has shown to be rich in vitamines almost invariably give a bright red colour when mixed with an equal volume of strong sulphuric acid, and this test is worth trying.

Testing Fish Meal.

Examine samples of fish meal. Note the appearance and characteristic smell. Heat with soda lime and note the very copious evolution of ammonia. Burn a little in a crucible and note the large proportion of ash which remains. Test the ash for calcium and for phosphoric acid.

Dried Blood.

Three by-products of the slaughtering of animals are valuable feeding stuffs. These are blood meal or dried blood, meat meal, and carcase meal. Blood meal or dried blood is made by drying part of the large volume of blood shed at the larger public slaughter houses or bacon factories, It is a fine dark brown powder containing about 80 per cent. of protein, and very little else besides water. A ration of not more than one or two ounces per day is a valuable addition to the diet of young growing pigs.

Meat Meal. Meat meal is made by drying and grinding the refuse other than bones from factories where meat is canned, or meat extract is made. It contains about 70 per cent. of protein and 10 to 15 per cent. of fat.

Carcase Meal. Carcase meal results when some or all of the bones are ground with the refuse meat. It contains about 50 per cent. of protein, 15 per cent. of oil, and over 20 per cent. of ash, which, as in the case of fish meal, is chiefly phosphate of lime.

Test these three products as you tested fish meal and compare the results.

Dried Yeast. Of recent years it has become increasingly the practice of some of the larger brewers and distillers to dry some of their waste yeast, and dried yeast is now regularly met with on feeding stuff markets. It contains about 50 per cent. of protein, practically no oil, about 35 per cent. of carbohydrates, and about 10 per cent. of ash. On account of its high content of protein it is a valuable feeding stuff for certain purposes. In addition to this it is credited with a very high content of the water soluble vitamines, which it will be remembered are also found in fresh green fodders. Like all feeding stuffs which are excessively rich in protein it should be used only in very small quantities. It is chiefly fed to pigs, and not more than from 1 to 8 ounces per head per day should be included in the ration.

Separated Milk. Separated milk and whey may be mentioned here as they are by-products of the dairy industry. Separated milk differs from whole milk in containing much less fat, since most of the fat has been removed in the cream. It contains about 90 per cent. of water, and 10 per cent. of solids, which are chiefly protein and milk sugar. To compare it with other feeding stuffs it is instructive to work out the composition of its solids. These contain about 37 per cent. of protein, about 53 per cent. of sugar, only a trace of fat, and from 9 to 10 per cent. of ash, which is chiefly phosphate of lime. Separated milk is,

therefore, rich in protein and ash, and is on this account a valuable feeding stuff. It is especially valuable for growing animals, and is chiefly used for calves and growing pigs. For the former the deficiency of fat is made up by addition of finely ground linseed meal and the finest grade of miller's offals, which together make an efficient cream substitute as it is called. For young pigs skim milk is used in place of water to wet their meal.

Whey.

Whey is the liquid from which the curd has been separated in cheese making. It is by no means so valuable as separated milk, as the curd has removed not only the fat but most of the protein. It only contains about 6½ per cent. of solids as compared with 10 per cent. in separated milk. The solids in whey contain about 10 per cent. each of protein and ash, only 3 per cent. of fat, and 77 per cent. of sugar. It is, therefore, a carbohydrate rich food. Its chief use is to supplement the meal ration of young pigs, for which purpose it possesses considerable value.

Cooked Foods.

There is a general idea among stock owners that cooking feeding stuffs makes them more nutritious because it increases their digestibility. Consequently some live stock owners cook some of their feeding stuffs, and in addition to this several brands of ready cooked feeding stuffs, especially maize, are on the market. As a general rule cooking does not increase digestibility, except in the case of maize and perhaps other very hard flinty grains.

CHAPTER XVII.

DIGESTIBILITY OF FOODS.

We have shown in the preceding chapters that the most abundant constituents of plants are the three great classes of compounds known as the carbohydrates, the fats, and the proteins. We know that plants or plant products of one kind or other form the diet of all our farm animals. We may assume, therefore, that these said carbohydrates, fats, and proteins between them provide in the main the food requirements of animals. Let us now turn our attention to the changes which these substances undergo in the animal's body from the time when they are eaten by the animal until what is left of them is excreted in the breath, in the dung, or in the urine.

Swallowing.

Food is taken in by the mouth, where it is chewed or masticated and mixed with the saliva so that it can be swallowed. It passes down the gullet or oesophagus into the stomach. In cattle and sheep the stomach is a complicated structure divided into four compartments. The largest of these, called the paunch or rumen, receives the food when swallowed. The food remains in the paunch for some time, and there undergoes fermentation. As soon as the animal gets an opportunity to rest, the food is regurgitated into the mouth and chewed or masticated a second time. This process of regurgitating the food and chewing it a second time is known as chewing the cud or rumination, and animals like cattle and sheep in which it occurs are called ruminants.

The Stomach.

After the second chewing is completed, the food is again

swallowed and passes down the gullet into the true stomach. In other animals, such as the horse and pig, in which rumination does not take place, the stomach consists only of a single compartment, which corresponds to the true stomach of cattle and sheep. In the true stomach the food is mixed with the gastric juice, a liquid secreted by the walls of the stomach. In due course the food leaves the stomach and enters the intestine, where it is mixed with other liquids, namely the pancreatic juice, which is secreted by the pancreas or sweetbread, the bile which is secreted by the liver, and the juice secreted by the walls of the intestine itself.

Digestive Juices.

The Intestine.

The intestine is a long coiled tube of varying size. The first coils are small in bore, and are known as the small intestine. The later coils are much larger, and are known as the large intestine or colon. At the point where the small intestine becomes the large intestine there is a blind-ended branch known as the caecum, or blind intestine, which in the horse is of enormous size. The last straight portion of the large intestine is known as the rectum, or straight intestine. This is the end of the intestine. From it the residue of the food is voided through the anus, which is situated under the root of the tail.

Digestibility.

If during a period of a week or a fortnight the food eaten by an animal is weighed, sampled, and analysed, it is possible to calculate the weight of dry matter consumed by the animal. In the same way the dung excreted by the animal during the same period can be collected, weighed, sampled, and analysed, and the total weight of dry matter excreted can then be calculated. On comparing the dry matter consumed with the dry matter excreted, it becomes obvious that during its passage through the animal's body more than half the food has disappeared.

In an experiment of this kind a sheep was found to have eaten during a certain period 879 gm. of dry matter in the form of hay, linseed cake, and silage. During the same

period the dry matter excreted in the form of dung was found to be 339 gm. The difference between these two weights, *i.e.* 879 — 339 gm., or 540 gm. had disappeared. During the period of experiment the sheep maintained its normal body temperature, carried on its normal vital functions, such as breathing, standing, eating, and made a small gain in live weight. The 339 gm. of its food which was voided as dung cannot have contributed to these results. The 540 gm. which disappeared must, therefore, have provided the energy necessary to maintain body temperature and vital functions, with a slight balance which supplied the material for a small gain in weight.

This is a fact from which many questions naturally arise.

Process of Digestion.

How did the 540 gm. disappear? What became of them? How were they used to maintain body temperature, to carry on vital functions, to produce increase in live weight? All these questions cannot be answered at once. We will first try to find out how the 540 gm. disappeared.

We know that the chief constituents of plants are carbohydrates, fats, and proteins. Presumably these substances formed the greater part of the diet of the sheep. It is much easier to experiment with one substance than with a mixture, so we will begin with one substance—starch. Looking back at Chapter III., we find that starch is insoluble in cold water, and that even in boiling water the solution which it forms is turbid and goes solid on cooling.

Now the food in its passage through the digestive organs is mixed with several different liquids. Probably these liquids are not without purpose. Possibly they may have taken part in causing the disappearace of the 540 gm. of food.

Digestion of Starch.

Make some starch solution by boiling about 1 gm. of starch in 100 c.c. of water. Cool to about 40° C., and measure 20 c.c. into a test-tube fixed in a large vessel of water kept at that temperature. Now add to the starch solution 1 c.c. of

liquor pancreaticus, a preparation of pancreatic juice which is made in large quantities for medicinal purposes. Before adding the liquor pancreaticus put a number of spots of iodine solution on a white tile or a piece of glazed paper, and to the first spot add a drop of the starch solution by means of a glass rod. Note the characteristic blue colour.

Immediately after adding the liquor pancreaticus, stir with a glass rod and transfer a drop of the mixture to a second spot of iodine. Probably the blue colour will still appear. Repeat this test every few seconds. Very soon no blue colour will be formed. Record the time which has elapsed since the liquor pancreaticus was added up to the point when the mixture first failed to give any blue colour with iodine. Let us suppose that this time was 95 seconds, then 1 c.c. of liquor pancreaticus changes all the starch in 20 c.c. of starch solution kept at 40° C. in 95 seconds. If the time taken was much less than this, repeat the experiment, using liquor pancreaticus which has been diluted by mixing with several times its volume of water.

Repeat the experiment exactly as before, but boil the liquor pancreaticus before adding it to the starch solution.

Repeat the experiment as before, but add to the mixture of starch solution and liquor pancreaticus 1 c.c. of dilute hydrochloric acid, and in another case 1 c.c. of dilute sodium carbonate solution. Note that the boiled liquor pancreaticus has no effect on the starch, that dilute hydrochloric acid prevents or greatly delays, whilst dilute alkaline solution of sodium carbonate quickens the rate of change of starch by liquor pancreaticus.

Finally, repeat the original experiment, but place the test-tube in cold water, which will be at 12° to 15° C., instead of 40° C. Note that the starch is changed slowly at the lower temperature.

Take one of the test-tubes in which the starch has lost all power of giving a colour with iodine, add a little Fehling's solution, and boil. The blue colour will disappear and a red

precipitate will be formed showing that the starch has been changed into sugar.

Ferments or Enzymes.

Liquor pancreaticus, which is simply a commercial preparation of the juice of the pancreas, evidently contains something which has the power of changing starch into sugar under certain circumstances. It acts on starch most rapidly at 40° C., which is about the temperature of an animal's body, and in the presence of a trace of sodium carbonate. A trace of acid delays the action. Boiling completely and permanently stops it.

Nearly all the digestive juices contain active substances of this kind. Such substances are called ferments, because of their similarity to the well-known ferment yeast, which changes sugar into alcohol. Yeast, however, is a living thing, a microscopic fungus, whilst the ferments of the digestive juices are chemical substances, and not living things. To distinguish them from living ferments like yeast they are called unorganised ferments, or, more frequently, enzymes. The characteristics of such enzymes are that they act most rapidly at about 40° C., the body temperature of animals, that their rate of action is greatly influenced by the acidity or alkalinity of their surroundings, and that they are destroyed by boiling.

The enzyme of the saliva is called ptyalin. It changes starch into sugar, and acts most rapidly in the presence of traces of alkali. The gastic juice contains an enzyme called pepsin, which in the presence of very dilute acid dissolves proteins. The intestinal juice contains several enzymes, among which may be mentioned erepsin, which dissolves proteins, and a peculiar enzyme which sets free the enzymes of the pancreatic juice. The pancreatic juice contains three very active enzymes, which, however, cannot become active until the enzyme of the intestinal juice has set them free. They are amylopsin, whose action on starch has already been studied above; trypsin, which dissolve proteins; and

steapsin, which splits fats into glycerol and soap. All these ferments act best in presence of a trace of alkali, preferably sodium carbonate.

Object of Digestion.

Now it is noteworthy that the action of all the above enzymes is to dissolve insoluble substances by converting them into soluble substances. Thus, insoluble starch is converted into soluble sugar, insoluble proteins become soluble, insoluble fats are changed into glycerol and soaps, which are both soluble. This conversion of the insoluble constituents of the food into soluble substances is the aim and object of digestion. Digestion is the first stage of the disappearance of the greater part of the food as it passes through the digestive organs.

Absorption.

Having been brought into solution by the process of digestion the food constituents are absorbed directly or indirectly into the stream of blood which flows through the blood vessels in the walls of the alimentary canal. In the blood they are carried to every part of the body, and used or stored as occasion demands.

How Digestibility is Measured.

On reference to the experiments described on p. 108, it will be seen that during a certain period a sheep ate 879 gm. of dry matter, and excreted 339 gm. in the form of faeces. The difference between these two figures, 540 gm., represents approximately the amount of the food which was digested. Calculating this as a percentage of the food consumed, it appears that of the dry matter of the given ration $\frac{540 \times 100}{879}$ or 61·5 per cent. was digestible.

By the same method carried out in greater detail it is possible to ascertain the digestibility of each separate constituent. Thus, in an investigation of the digestibility of oat and tare silage, a sheep was found to eat 3,000 gm. per day. The silage contained 72·7 per cent. of water, and, consequently, 27.3 per cent. of dry matter. The amount of

faeces excreted per day was 569 gm., which was found to contain 292 gm. of dry matter. The dry matter of the silage and of the faeces was found by analysis to contain :—

Composition of Dry Matter per cent.

	Silage.	Faeces.
Protein	12·55	12·02
Fat	4·32	3·27
Carbohydrates	45·57	37·15
Fibre	29·44	35·03
Ash	8·12	12·53
	100·00	100·00

From these figures the amounts of protein, fat, carbohydrates and fibre eaten and excreted per day were calculated. Thus :—

3,000 gm. silage contain $3{,}000 \times 27{\cdot}3 \div 100 = 819$ gm. dry matter.

819 gm. dry matter contain $819 \times 12{\cdot}55 \div 100 = 103$ gm. protein.

292 gm. dry matter of faeces contain $292 \times 12{\cdot}02 \div 100 =$ 35 gm. protein.

The sheep, therefore, ate per day 103 gm. of protein and voided in his faeces 35 gm. He digested, therefore, $103 - 35 = 68$ gm., which corresponds to $\frac{68 \times 100}{103}$, or 66 per cent. of the protein he consumed.

Similar calculations show that the digestibility of the other constituents were: fat, 73 per cent., carbohydrates, 70 per cent., fibre 57 per cent., ash 44 per cent.

Digestibility Coefficients.

These figures give the percentage of the various food constituents of oat and tare silage which are digestible by sheep. Such percentage digestibilities are known as digestibility coefficients. Tables of digestibility coefficients for many feeding stuffs when fed to different kinds of animals are given in *The*

Scientific Feeding of Animals by Kellner, published by Duckworth and Co., and in *Feeds and Feeding*, by Henry and Morrison, published by Lake Side Press, Chicago.

These coefficients show that all kinds of animals do not possess exactly the same powers of digestion. Cattle and sheep are very similar. Both digest coarse fodders better than horses do. Pigs resemble cattle in their powers of digestion, but, although they can digest foods low in fibre as well as cattle can, they do not do well on fibrous foods.

From the analysis of a feeding stuff and the percentage digestibility coefficients it is easy to calculate the percentage of digestible nutrients. This is how the tables in *Rations for Live Stock* and most other books were compiled.

CHAPTER XVIII.

FEEDING STANDARDS. COMPARATIVE SLAUGHTER AND BALANCE METHODS.

Since the first serious attempts were made about a century ago to apply scientific methods to the feeding of animals it has always been the aim of the scientific investigator to establish some kind of quantitative connection between the weight of an animal and the amount of food required to enable it to produce a certain result in the form of growth, milk, or work.

Hay Equivalents.

About that date the German experimenter, Thaer, evolved a method of investigation which was capable of giving a definite result.

Thaer's method was to feed an animal on hay, weighing it at intervals, and thus determining its rate of growth. Part of the hay was then replaced by another feeding stuff, and the amount of the latter increased or decreased until the original rate of growth was again obtained. An instance will perhaps make the method clear. An ox consuming per day 30 lb. of hay was found to increase in weight at the rate of 1¼ lb. per day. The hay ration was then reduced to 20 lb., and the 10 lb. of hay replaced by 20 lb. of swedes. Weighings showed that the growth rate as a result of this replacement fell to ¾ lb. per day. The swede ration was then increased to 30 lb. per day, when the growth rate became about 1 lb. per day. A further increase to 40 lb. per day of swedes gave a growth rate of 1¼ lb. per day, which was the original rate, This showed that 40 lb. of swedes had the same growth producing value as 10 lb. of hay.

Thaer then took as his standard 100 lb. of hay. The amount of swedes required to produce as much growth as 100 lb. of hay would be 400 lb., and this he called the hay equivalent of swedes, Working in this way he was able to measure the hay equivalents of a number of feeding stuffs. A live-stock owner could by using these figures compare the growth producing values of these feeding stuffs, and further he would know the proportions in which he could replace one of them by another without altering the rate of growth of his animals.

Thaer's next step was to state as the result of his experience the ration of hay required to maintain a normal rate of growth in cattle and sheep, and a normal amount of work in horses. These rations were called Thaer's feeding standards. They were generally useful, because by using his hay equivalents stock owners could work out rations for their animals by replacing all or part of the hay ration by other feeding stuffs in proportion to their hay equivalents.

The method, however, had two very obvious disadvantages: hay is notoriously variable in quality, and consequently a most unsuitable feeding stuff for adoption as a standard. And again, it is exceedingly difficult to base accurate measurements on weighings of a live animal. There are so many sources of error in determining the live-weight, which is always changing, sometimes very suddenly, as when the animal excretes urine or dung.

Grouven's Standard Rations.

At the time when Thaer was experimenting, chemical analysis was not generally applied to the investigation of feeding stuffs. As the use of this method extended, it became obvious that animals required not simply so many pounds per head per day of food, but such an amount of food as would supply them with a certain amount of protein, fat, and carbohydrate, and standard rations for various kinds of live stock, stated in terms of proteins, fats, and carbohydrates, were suggested by Grouven in 1859.

Wolff's Standard Rations.

The spread of this knowledge was largely due to a German firm of publishers who issued every year an agricultural calendar. In 1864 they arranged that Wolff, who was at that time the leading authority on the feeding of animals, should prepare for their calendar a series of standard rations stating in terms of digestible protein, fats, and carbohydrates, the requirements of all classes of animals under varying conditions. These standard rations were revised annually up to 1896, by Wolff, in the light of his continued experience. They were copied into the text-books of all countries, and became known as Wolff's feeding standards.

After 1896 the revision of Wolff's feeding standards was entrusted to Lehmann, and the revised rations, known as the Wolff-Lehmann feeding standards, appeared annually in the German Agricultural Calendar from 1897 to 1906, and very quickly replaced the older Wolff standards in all the text-books. After 1906 new standards were prepared by Kellner, which will be discussed later.

Comparative Slaughter Method.

Meantime two other methods of investigation had been introduced. Lawes and Gilbert, at Rothamsted, had used what is known as the comparative slaughter method for studying two very important questions, the relation between the consumption of fodder and the amount of saleable carcase produced, and the sources of fat in the animal body. The essential feature of this method is that a number of animals are selected as carefully as possible for uniformity in breed, age, weight, and condition, and some of them are slaughtered and their carcases sampled and analysed. The rest are then fed on a weighed and analysed diet for a given time, or to a given condition of fatness, when they are slaughtered, and their carcases sampled and analysed. It is then assumed that the composition of the carcases of the first lot slaughtered was the same as that of the survivors which were subsequently fed and slaughtered later. The weight of carcase, fat, bone,

flesh, and of protein, fat, water, ash, found in the first lot slaughtered, subtracted from the weights of these constituents found in the second lot slaughtered can then be compared with the amount of fodder consumed between the two dates of slaughtering, and a definite connection can thus be found between the consumption of fodder and the amounts of carcase, fat, bone, flesh, and of protein, fat, water, and ash produced.

Source of Fat in the Body.

By this method Lawes and Gilbert definitely proved that the chief source of fat in the animal body is the carbohydrate in the food. They also showed that a fattening animal retains in its body not more than about 5 per cent. of the protein it consumes, whilst a young growing animal may retain and convert into flesh as much as 25 per cent.

This method of comparative slaughter is expensive, and entails a very great amount of labour in sampling and analysing the carcases. After Lawes and Gilbert it was not used for many years, but it is being used again at the present time in Cambridge and elsewhere to investigate several important and disputed points in the process of winter-fattening of cattle.

Balance Method.

The second method of investigation referred to above is known as the balance method. By weighing, sampling, and analysing the diet of an animal it is possible to record the exact weights of the various constituents consumed by the animal during any given period. These weights can be stated both in terms of protein, fat, carbohydrates, water, and ash, and in terms of nitrogen, carbon, hydrogen, sulphur, phosphorus, and the other elements included in the fodder, if the analyses are sufficiently complete.

By collecting, sampling, and analysing the urine and dung voided during the same period it is also possible to record the weights of the same constituents excreted by the animal, So far this is the same method as was used for determining the

digestibility of fodders (Chapter XVII). Carried only thus far, however, it does not enable the investigator to strike a complete balance between the constituents of the fodder consumed and the total excreta of the animal, for it takes no account of the gases excreted in the breath and from the alimentary canal.

Respiration Chamber.

Certain investigators, notably Kellner, devised the apparatus known as the respiration chamber, which enabled them to sample and analyse also the gaseous excreta, and thus to strike a complete balance. A respiration chamber consists of a chamber large enough to accommodate the animal in reasonable comfort. This chamber can be made air tight except for a pipe which admits air for ventilation, and a corresponding pipe from which the ventilating air is drawn by means of a pump. The air thus drawn through the chamber is measured by a meter, passed through an absorbing apparatus which takes out all the water vapour, and then through a second absorbing apparatus which takes up all the carbon dioxide.

For flesh eating animals this would be sufficient, but for farm animals, especially cattle and sheep, it is necessary also to estimate the marsh gas which is formed by bacterial digestion of fibre and other carbohydrates. This is effected by making a special analysis of samples of the air drawn out of the chamber.

Whilst the animal is in the chamber its dung is collected in a bag as in digestibility experiments, and its urine is also collected by means of a funnel slung in position by girths and connected by a rubber tube to a suitable receptacle. The dung and urine are then weighed, sampled, and analysed. In accurate experiments the scurf brushed from the animal's coat is also weighed and analysed.

In this way all the necessary figures are obtained to enable the investigator to draw up a complete balance between say the carbon, nitrogen, etc., consumed in the food and the same

constituents excreted during the same period in the dung, urine, and breath, and in the form of marsh gas.

The following very much simplified example of a balance experiment will make the method clear:—

Balance experiment with a steer weighing 1,000 *lb.*

Ration 14 lb. per day of meadow hay.

Carbon Balance.		*Nitrogen Balance.*	
14 lb. hay contained	5·2 lb. C.	14 lb. hay contained ...	·22 lb. N.
Excreta contained—		Excreta contained—	
Dung ...	·80 lb. C.	Dung ...	·10 lb. N.
Urine ...	·08 ,,	Urine ...	·12 ,,
Breath	4·11 ,,	Breath ...	—
Marsh gas	·21 ,,	Marsh gas	—
	5·2 lb. C.		·22 lb. N.

In the above experiment it will be noticed that both the carbon and nitrogen consumed in the ration of hay are exactly balanced by the carbon and nitrogen in the excreta. Such an experiment would extend over several days. The figures given are the average consumption and excretions per day. The exact balance between consumption and excretion of carbon and nitrogen shows that on the ration employed the animal's body neither gained nor lost either carbon or nitrogen. It remained in what is called "carbon and nitrogen equilibrium."

Maintenance Ration.

Since nitrogen and carbon are the two chief constituents of flesh and fat, the animal neither gained nor lost flesh or fat on the ration of 14 lb. hay per day. A ration which maintains an animal's flesh and fat constant in this way is called a maintenance ration, and it will be instructive to work out the weights of protein, fat, etc., in this ration. The percentage composition of meadow hay of good quality is :—

	Total.	Digestible.
Water	14·3	—
Protein	9·7	5·4
Fat...	2·5	1·0
Carbohydrates	41·0	25·7
Fibre	26·3	15·0
Ash	6·2	—
	100·0	—

Consequently 14 lb. of such hay, which was the ration employed, contain the following amounts of total and digestible constituents, and these are the amounts which will maintain a 1,000 lb. steer so that he neither gains nor loses flesh or fat.

Maintenance ration of 1,000 *lb. steer.*

	Total.	Digestible.
Protein	1·36 lb.	·75 lb.
Fat...	·35 „	·14 „
Carbohydrates	5·74 „	3·60 „
Fibre	3·68 „	2·10 „

If the hay had been rather poorer in protein as a matter of fact the nitrogen balance would probably have still been maintained in equilibrium, for the requirement of protein for maintenance of a 1,000 lb. steer is on an average nearer ·6 lb. of digestible protein than ·75 lb.

This balance method of investigation was a great advance in methods of studying problems of animal nutrition, for it enabled the investigator to compare food consumption with flesh and fat production without his having to rely on such inaccurate measurements as live-weight, and without assuming that the composition of the carcase of one animal is the same as that of another as was necessary in the comparative slaughter method. Another instance, again very much simplified, will make clear the further possibilities of the method.

This experiment is supposed to have been carried out immediately after the last one. The same animal was used, but the ration of 14 lb. of the same hay was supplemented by the addition of 2 lb. per day of pure starch. The sampling and analysis of the excreta were carried out as before with the following results:—

Carbon balance of 1,000 *lb. steer.*

Ration 14 lb. meadow hay and 2 lb. starch.

14 lb. hay contained as before		5·20 lb. C.
2 lb. starch contained		·88 ,,
Total carbon consumed per day ...		6·08 ,,
Excreta contained—		
Dung	·80 lb. C.	
Urine	·08 ,,	
Breath	4·495 ,,	
Marsh gas	·32 ,,	
		5·695 ,,
Balance: Carbon retained in body		·385 ,,
		6·080 ,,

There is no need to repeat the statement of the nitrogen balance which remained as before, showing no loss or gain of nitrogen.

The experiment shows that the addition to the maintenance ration of 2 lb. per day of starch caused the retention in the body of ·385 lb. of carbon. Now the two carbon containing constituents of the body are proteins and fats. None of this carbon can, however, have been retained as protein for the equilibrium of the nitrogen balance shows that there was neither gain nor loss of protein. It must therefore have been retained in the form of fat. Fat contains 77 per cent. of carbon. Consequently ·385 lb. of carbon is equivalent to $\cdot 385 \times \frac{100}{77} = \cdot 5$ lb. of fat. Two pounds of starch when

added to a maintenance ration produced in the animal's body the storage of half-a-pound of fat. This result was not obtained in one experiment. It was the average of many. Usually an exact nitrogen balance was not obtained, in which case a correction was made for the carbon in the protein stored or lost as shown by the nitrogen balance. From the average of many such experiments, however, Kellner established the important fact that for every pound of fat stored in its body an animal must consume 4 lb. of starch (or its equivalent in the form of other food constituents).

Kellner also carried out other experiments on the same lines by adding to the maintenance ration pure protein or pure fat instead of starch. From these experiments he found that the quantities of the three main food constituents required to produce 1 lb. of fat in the body were:—

Quantities required to produce 1 lb. fat.		*Weight of fat formed by 1 lb. of*	
Protein	4·25 lb.	Protein	·235 lb.
Fat in coarse fodders	2·11 ,,	Fat in coarse fodders	·474 ,,
,, in cereals ...	1·90 ,,	,, in cereals ...	·525 ,,
,, in oil seeds ...	1·67 ,,	,, in oil seeds ...	·600 ,,
Carbohydrates ...	4·00 ,,	Carbohydrates ...	·250 ,,

CHAPTER XIX.

STARCH EQUIVALENTS—KELLNER'S AND OTHERS.

In the last chapter we set out to discuss feeding standards, but were compelled to digress in order to study the balance method of investigation. We found that by the use of this method Kellner was able to measure with considerable accuracy the weights of the various food constituents required to produce the storage of 1 lb. of fat in the body of a steer in store condition.

Calculation of Fat produced by Food

Kellner's idea in making these determinations was that they would enable him to calculate from the percentage of digestible nutrients in a feeding stuff how much of it would be required to produce a given weight of fat. He proceeded to make the calculation thus:—100 lb. of linseed cake contains 25·3 lb. of digestible protein, 8·7 lb. of digestible fat, and 33·0 lb. of digestible carbohydrates and fibre. Multiplying each of these figures by the weight of fat formed from 1 lb. of protein, fat, and carbohydrate respectively, we get the weight of fat which should be formed by the consumption of 100 lb. of linseed cake. Thus—

25·3 lb.	digestible	protein × ·235	= 5·95 lb.	fat
8·7 lb.	„	fat × ·600	= 5·22 „	„
33·0 lb.	„	carbs. and fibre × ·250	= 8·25 „	„
100 lb. linseed cake should therefore form			19·42 „	„

Having made this calculation, Kellner now proceeded to test it by the balance method. He adjusted the hay ration of a store bullock to maintenance, and determined the carbon and nitrogen balance. He then added to the ration a known weight per day of linseed cake, and again determined the carbon and nitrogen balance. The balance showed that the animal was retaining a certain weight of carbon in his body. This weight of carbon was calculated as fat, and it was found that fat formation from linseed cake was at the rate of 18·84 lb. of fat from 100 lb. of cake. This is distinctly lower than the figure which was calculated. It is, in fact, only 97 per cent. of the calculated figure.

Such a small difference as this, only amounting to 3 per cent., might well be due to experimental error, but Kellner then proceeded to compare the fat-producing values of about a dozen typical feeding stuffs as found by calculation and as determined directly by balance experiments. He found that in every case the actual experimental values were lower than the calculated values. A few of his figures are tabulated below:—

Name of Feeding Stuff.	Fat produced per 100 lb. Calculated.	Fat produced per 100 lb. Found.	Percentage of calcd. actually Found.
Linseed cake	19·42	18·84	97
Swede turnips	2·147	1·825	85
Meadow hay—good ...	11·045	7·400	67
Oat straw	9·930	4·270	43

Whilst the 3 per cent. discrepancy between the values calculated and found in the case of linseed cake might well have been due to experimental error, the differences in the case of the other feeding-stuffs, which are in order 15 per cent., 33 per cent., and 57 per cent., could not possibly be due to this cause. They were certainly real differences.

Work of Digestion.

It will be noted that they are larger in the more fibrous foods. Kellner noticed this, and concluded, therefore, that his directly determined experimental results were lower than his calculated results because his original fat-producing values for pure protein, fat, and carbohydrates were determined by using the pure substances, whilst in the case of the actual feeding stuffs, these constituents were, so to speak, entangled in the fibrous constituents of the feeding stuffs, from which the animal must separate them in the process of digestion. This entailed longer and more strenuous work for the digestive organs, which used up a portion of the nutritive constituents of the feeding stuffs which might otherwise have been converted into fat.

On this assumption the percentage figure given in the last column measures the proportion of the total possible fat-producing power of the feeding stuff which can actually be converted into fat, the rest having been used up in what Kellner called the work of digestion.

Value Numbers.

Having determined the actual fat-producing power of a dozen typical feeding stuffs, and having compared these values with the calculated values, Kellner established a definite relation between the proportion of fibre in a feeding stuff and the percentage of its calculated fat-producing power which could be actually converted into fat. By means of this relation he was able to assign to other feeding stuffs figures, based on their proportion of fibre, which indicated the percentage of their total calculated fat producing power which could actually be converted into fat. These figures he called value numbers, which he abbreviated into the letter V.

Calculation of Fat produced by Foods.

Armed with these V numbers, and with his original figure for the fat producing power of pure proteins, fats, and carbohydrates, he was able to calculate the actual fat producing power of any feeding stuff of which he knew the content of digestible nutrients.

Thus:—Oats contain 8·0 per cent. digestible protein, 4 per cent. digestible fat, 44·8 per cent. digestible carbohydrates, and 2·6 per cent. of digestible fibre, and the V number of oats is estimated from their proportion of fibre to be 95.

8·0 lb. digestible	protein × ·235 would produce	1·88 lb. fat.
4·0 lb. ,,	fat × ·525 would produce ...	2·10 ,, ,,
44·8 lb. ,,	carbohydrates × ·25 would produce	11·20 ,, ,,
2·6 lb. ,,	fibre × ·25 would produce ...	·65 ,, ,,

Total calculated fat production per 100 lb. = 15·83 ,, ,,

Actual fat production per 100 lb. = 15·83 × 95 ÷ 100 = 15·0 lb.

Such calculations were made for about 300 different feeding stuffs, and the results are given in Kellner's book, which has been translated into English by Goodwin, and published by Duckworth & Co., under the title, *The Scientific Feeding of Animals.*

Starch Equivalents.

Kellner does not, however, give the fat-producing power of the various feeding stuffs in terms of lb. of fat produced by 100 lb. of the feeding stuff. His figures are given in terms of the number of pounds of starch which would be required to produce the same amount of fat as 100 lb. of the feeding stuff. Thus.—

100 lb. oats produce	15·0 lb. fat
1 lb. starch produces	·25 ,, ,,
4 lb. starch produce	1 ,, ,,

100 lb. oats, therefore, produce as much fat as

15·0 × 4 = 60 lb. starch.

This figure, 60 lb. of starch, which is the amount of starch which would produce as much fat as 100 lb. of oats, is called the starch equivalent or the starch value of oats. Kellner, in the appendix to his book, gives such starch equivalents for about 300 feeding stuffs.

Meaning of Starch Equivalent.

These starch equivalents, as is shown by the method used in their determination, really attempt to measure the fat-producing value of feeding stuffs when fed to steers in store condition, and it is important to remember this. They have been widely, but not universally, accepted as measuring the real value of feeding stuffs for all kinds of production, not only of fats, but of growth, milk, and work. Their usefulness for measuring the value of feeding stuffs for all these purposes is undoubted, but it has, perhaps, stretched rather unduly their original meaning, especially in the case of milk production. There is some evidence to show that Kellner's starch equivalents do not include a sufficiently high value for protein to make them really accurate as a measure of milk-producing value.

To return at last to our discussion of feeding standards, it is obvious from Kellner's work on the real fat-producing value of feeding stuffs, which showed that in very fibrous materials the actual productive value was less than half the value calculated from the content of digestible nutrients, that standards given in terms of digestible nutrients leave much to be desired. Evidently the digestible nutrients of feeding stuffs containing little fibre may be twice as valuable as the same quantity of digestible nutrients in feeding stuffs rich in fibre.

Rationing by Starch Equivalents.

Kellner followed up his work by giving feeding standards in terms of his starch equivalents, which possessed two very obvious advantages. The standard could be expressed in a single figure —so many pounds per head per day of starch equivalent—instead of three figures, one for protein, one for fat, and one for carbohydrate. The figure is also a net figure directly related to the result it may be expected to produce. Thus, a steer getting 6 lb. per day of starch equivalent in addition to his maintenance ration may be expected to lay on 1½ lb. of fat per day, since 1 lb. of starch or starch equivalent produces ¼ lb. of fat.

Experience has indicated a somewhat similar relation in the case of milk production, in which case $2\frac{1}{2}$ lb. of starch equivalent is required to produce 1 gallon of milk. Up to the present no definite numerical relation has been established between consumption of starch equivalent and production of work. There is no doubt that such a relation exists. The difficulty in discovering it lies in the fact that there is no practical method of measuring the amount of work done by a horse under farming conditions. Even if a definite numerical relation were discovered it would be incapable of practical application because of the difficulty of expressing the varying activities of the horse in foot-pounds of work. Although it is possible to state food requirements as starch equivalent in one figure, this one figure must always be accompanied by the qualification that it must include a given quantity of protein. Thus it does not suffice to state that a fattening ration for a 9 cwt. steer is 13 lb. per day of starch equivalent, for this might be made up of mangolds, straw, and maize, which might not provide sufficient protein. It must also be stated that the 13 lb. of starch equivalent must include 1·5 lb. of digestible protein.

Other Starch Equivalents.

The term starch equivalent, originally used by Kellner, has been used by other writers in several different senses. Kellner's starch equivalents, as explained above, were measures of the net or actual fat-producing values of feeding stuffs. The obvious advantage of expressing the nutritive value of a feeding stuff by a single figure has tempted several writers to use the term in quite a different sense. As this has caused much confusion, it is necessary to make a short digression on the subject.

The digested constituents of the food are oxidised in the body with the production of heat, each constituent producing when oxidised a definite quantity of calories or heat units. Thus, 1 gm. of starch, sugar or other carbohydrates

when completely oxidised gives out 4,100 calories: 1 gm. of fat, 9,300 calories; 1 gm. of protein, 5,800. Digestible carbohydrates, however, before they are absorbed from the alimentary canal, are attacked by bacteria which, on the average, take a toll of about 8 per cent., which they transform into marsh gas, a combustible product which leaves the body unoxidised. Proteins, again, are not completely oxidised by the animal, but leave the body in the urine, in the form of urea, uric acid, and other similar products which are still capable of further oxidation, and, therefore, still contain a proportion of the heat of the protein. Fats, as estimated in feeding stuffs by extraction with ether, are not quite pure, since ether dissolves small quantities of other materials. These impurities have a lower heat value than pure fats.

These facts are tabulated below:—

Gross and Net Heat Values of Food Constituents.

	Heat of Combustion per gm. calories.	Deductions—calories.			Net Heat Value to Animal. calories per gm.
		Marsh Gas Fermentation.	calories left in Urea, Uric Acid, etc.	Lower Heat Value of Impurities.	
Protein ...	5800		1100		4700
Fat	9300			500	8800
Carbohydrates..	4100	340			3760

These figures show that from 1 gm. of protein an animal obtains 4,700 calories; from 1 gm. of fat, 8,800 calories, and from 1 gm. of of carbohydrates, 3,760 calories. The relative heat-producing values, taking that of starch as 1, are, for protein, $\frac{4700}{3760}$, or 1·25, and for fats, $\frac{8800}{3760}$, or 2·3.

Using these relative heat-producing values, it is possible to calculate the amount of starch which would be required to

yield to an animal the same amount of heat as 100 lb. of any feeding stuff, for instance, linseed cake, as follows:—

Digestible Nutrients per 100 lb.

Protein	... 25·3 × 1·25	=	31·6
Fat	... 8·7 × 2·3	=	20·0
Carbohydrates ...	... 28·5 × 1·0	=	28·5
Fibre	... 4·5 × 1·0	=	4·5
			84·6

This calculation shows that 100 lb. of linseed cake would produce inside an animal as much heat as 84·6 lb. of starch. Figures calculated in this way have been called starch equivalents by several writers. They are, however, quite distinct from Kellner's starch equivalents, since they measure, not the net productive value, but the gross heat-producing value of feeding stuffs. This distinction has been recognised by calling Kellner's starch equivalents production starch equivalents, and starch equivalents calculated as above maintenance starch equivalents. The reason for using these names will be dealt with in a later chapter.

Meanwhile other names have also been used, as, for instance, net digestible energy for Kellner's starch equivalents, and gross digestible energy for starch equivalents calculated on the heat production basis.

The important point to remember, however, is that Kellner's starch equivalents, determined by ascertaining, by the balance method, the amount of fat stored in the body of an animal by the consumption of a certain weight of feeding stuff, are the best measure of net productive value. The other so-called starch equivalents measure only the gross heat-producing value of feeding stuffs, and do not attempt to specify what proportion of the heat can be used for productive purposes.

CHAPTER XX.

HEAT MEASUREMENTS. METABOLISABLE ENERGY.

In the last chapter we saw that Kellner, by means of a respiration chamber large enough to accommodate an ox, was able to apply the balance method to the investigation of nutritional problems, with the result that he was able to measure the net productive value of feeding stuffs which he expressed as starch equivalents.

Meantime, Armsby had constructed at the Pennsylvania experiment station in America, another complicated instrument called an animal calorimeter. By the aid of this instrument he and his colleagues attacked the same problem as Kellner had done, but in another way. Kellner's observations had enabled him to record the quantity of feeding stuff required to produce the storage of a definite quantity of fat. The Pennsylvania workers directed their attention to observing the quantity of heat given out by animals from the consumption of certain quantities of feeding stuffs.

Heat Measurements.

The word calorimeter means an instrument for measuring quantities of heat. A quantity of heat is measured by finding how much water it will warm through a definite temperature interval.

Heat Units.

That quantity of heat which will warm 1 gm. of water through 1° C. is called one unit of heat or one calorie. For many purposes this unit is inconveniently small, in which case it is replaced by the large

Calorie, written with a capital C, which is the amount of heat required to warm 1 kilogram = 1,000 gm. of water through 1° C. Even this large Calorie is sometimes too small and is replaced by 1 therm which is equal to 1,000 large Calories or 1,000,000 small calories. It is important to remember the relation between these three heat units because all of them are used in the various books which treat of the nutrition of animals.

Heat of Combustion.

The first step in investigating the value of feeding stuffs from the point of view of their value for heat production, is to measure the gross amount of heat which their chief constituents can produce when completely burned. Such measurements are made by an instrument called a bomb calorimeter, which consists essentially of a heat-measuring vessel which holds the water to be warmed by the combustion of the substance under investigation, and a steel bomb in which the combustion actually takes place. The procedure is as follows:—

A small quantity of the substance under experiment, compressed into a pellet and accurately weighed, is placed inside the bomb, being supported in a small crucible attached to the lid of the bomb. The bomb is then filled with oxygen under pressure, and immersed in the water in the calorimeter vessel. The substance is set on fire by a very fine wire which is heated electrically. It burns rapidly in the compressed oxygen, the heat it gives out in burning being conducted through the walls of the bomb to the water in the calorimeter. The rise in temperature of the water is measured by a specially constructed thermometer which can be read to ·001° C. The rise of temperature in degrees C., multiplied by the weight of water in grams, gives the heat in calories given out by the burning of a known weight of the substance. From this the heat given out by 1 gm. of the substance is calculated. This is the heat of combustion. It is by experiments of this kind that the heats of combustion of proteins, fat, and carbo-

hydrates quoted in Chapter XIX., p. 130 were determined, namely:—

	Heats of combustion per gram.	per lb.
Protein ...	5800 calories = 5·8 Calories	2633 Calories.
Fat	9300 calories = 9·3 Calories	4222 Calories.
Carbohydrates	4100 calories = 4·1 Calories	1861 Calories

Heat Production in the Body. Protein.

In determining heats of combustion by this method, the substances are burnt in compressed oxygen, which ensures their complete combustion to carbon dioxide and water, and in the case of proteins, nitrogen and ash. This is not exactly what happens in the animal's body. For instance, when protein is oxidised by an animal, most of its carbon is oxidised to carbon dioxide and most of its hydrogen to water, but some of its carbon and hydrogen remain in combination with all its nitrogen forming such compounds as urea, uric acid and hippuric acid, which are excreted in the urine. These excretory products are capable of burning, and therefore still contain some of the chemical energy which was responsible for the heat of combustion of the protein. To ascertain the net heat producing value of the protein to the animal, the heat of combustion of the excretory products must be subtracted from the heat of combustion of the protein.

To find the heat of combustion of the excretory products corresponding to 1 gm. of protein, the following method is used. Referring to the nitrogen balance experiment quoted in Chapter XVIII., p. 120, it appears that the steer under experiment consumed ·22 lb. of nitrogen per day and excreted ·10 lb. as undigested materials in his dung, and ·12 lb. as excretory product in his urine. He was consuming, therefore, per day, ·12 lb. of digestible nitrogen, which is equivalent to ·12 × 6·25 lb. = ·75 lb. of digestible protein. This quantity is ·75 × 454 gm. = 340 gm. of digestible protein per day.

The whole of his urine was collected for several days, mixed, and accurately measured. The average volume excreted per day was found to be 4·75 litres. This volume, therefore, contains the excretory products corresponding to the consumption of 340 gm. of digestible protein. The excretory products corresponding to 1 gm. of digestible protein are, therefore, contained in $\frac{4 \cdot 75}{340}$ litres = 14 c.c. This volume of 14 c.c. of urine is then measured out into an evaporating dish and evaporated almost to dryness. It is then transferred to the small platinum cup of the bomb calorimeter, and dried completely in the water oven. The usual thin piece of iron wire is made to dip into the solid residue, the cup attached to the lid of the bomb, the ends of the wire secured to the two platinum rods, and the heat of combustion of the dried excretory products determined in the usual way.

The result shows that on the average the heat given out by burning the excretory products corresponding to 1 gm. of digestible protein is 1,100 calories. Subtracting this from the heat of combustion of 1 gm. of protein, the net heat producing value per gram of protein to the animal is 5,800 − 1,100 calories = 4,700 calories, or 4·7 Calories. This is equivalent to 4·7 × 454 Calories, or 2,133 Calories per lb.

Carbohydrates. The case of carbohydrates is rather different. The carbohydrates which are actually absorbed from the alimentary canal, after having been converted into sugar in the process of digestion, are completely oxidised to carbon dioxide and water, and therefore yield to the animal their full heat of combustion per gram. But before they are absorbed, the fermentative bacteria of the alimentary canal take toll of them to the extent of about 8 per cent., which is converted into marsh gas and voided in that form by the animal. Marsh gas can burn, and in doing so gives out heat, so that a proportion of the heat value

of the carbohydrates consumed by an animal is lost in this way.

Referring back to the carbon balance experiment described in Chapter XVIII., p. 120, it appears that out of 3·60 lb. of digestible carbohydrates consumed by the steer, the loss as marsh gas was equal to ·21 lb. of carbon, which is equivalent to ·28 lb. of marsh gas. This corresponds to a loss of ·08 lb. of marsh gas for every pound of digestible carbohydrates eaten. The heat of combustion of marsh gas per lb. is 1925 Calories. The heat given out by ·08 lb. would therefore be ·08 × 1925 Calories = 154 Calories. Deducting this from the heat of combustion of carbohydrates per lb., the heat producing value of digestible carbohydrate to the animal is 1,861 — 154 Calories = 1,707 Calories per lb., which is equivalent to 1,707 ÷ 454 Calories = 3·76 Calories per gram.

Fats.

The case of fats is again different. Fats are completely oxidised in the body to carbon dioxide and water, and they do not suffer any loss from the action of fermentative bacteria. The whole of their heat of combustion is therefore available to the animal. But all fats do not possess exactly the same chemical composition. Consequently the heat of combustion of all fats is not exactly the same. Further, the analytical method used for estimating fats in feeding stuffs is not quite exact, since ether dissolves from feeding stuffs small quantities of materials which are not fats. These impurities in what may be called analytical fat yield little heat to the animal. For these reasons it has been found necessary to reduce the figure for the heat of combustion of digestible fats from 9,300 calories per gm. to 8,800 calories which is equivalent to 8·8 Calories per gram, or practically 4,000 Calories per lb. We are now in possession of the necessary figures to enable us to calculate from its content of digestible nutrients the heat-producing value of a feeding stuff to an animal. These figures are:—

Heat producing values to the animal.

	Calories per lb.	Per gram.
Protein	2133	4·7
Fat	4000	8·8
Carbohydrates ...	1707	3·76

Metabolisable Energy. The method of using these figures is as follows:—

Heat producing value of linseed cake.

Linseed cake contains per 100 lb.			
Digestible protein ...	25·3 × 2133 =	53965	Calories.
Digestible fat	8·7 × 4000 =	34800	,,
Digestible Carbohydrates	28·5 × 1707 =	48650	,,
Digestible fibre	4·5 × 1707 =	7682	,,
		145097	,,

This is an inconveniently large figure, so it may be stated as 145 therms.

The heat producing value of linseed cake is therefore 145 therms (see p. 133) per 100 lb., or 1·45 therms per lb.

This figure is called by the American investigators the metabolisable energy of linseed cake. It is essentially the same figure as that given on p. 131 for the so-called maintenance starch equivalent or gross digestible energy, namely 84·6 lb. starch. Starch is of course a carbohydrate, and its heat producing value to the animal is therefore 1,707 Calories per lb. The heat producing value of 84·6 lb. of starch is therefore 84·6 × 1,707 Calories = 144,412 Calories, or 144 therms per 100 lb., or 1·44 therms per lb.

Evidently metabolisable energy and maintenance starch equivalent or gross digestible energy are the same, except that metabolisable energy is expressed in terms of heat units—Calories or therms—and maintenance starch equivalent or gross digestible energy in terms of starch. The latter

can be converted into the former by multiplying by 1,707, the heat producing value of 1 lb. of starch.

An alternative method of ascertaining the metabolisable energy is frequently used. An animal is fed upon a weighed ration of the feeding stuff under investigation, and its dung and urine collected, weighed and sampled as in carrying out digestibility or balance experiments. The gross heat of combustion of the feeding stuff per gm. is then determined by the bomb calorimeter, and the quantities of heat given out by portions of dried dung and dried urine corresponding to 1 gm. of the feeding stuff are also determined.

The sum of these quantities is then subtracted from the gross heat of combustion per gram of the feeding stuff, and from the remainder, in the case of ruminants, a further deduction is made of the calculated heat of combustion at 4·1 Calories per gram of 8 per cent. of the digestible carbohydrates and fibre contained in 1 gm. of the feeding stuff. The final remainder is the metabolisable energy of the feeding stuff in Calories per gram, and this can readily be converted into therms per lb.

CHAPTER XXI.

NET ENERGY.

Having carried out these preliminary investigations which led to the determination of the theoretical heat producing values of feeding stuffs, the Pennsylvania investigators next proceeded to use their animal calorimeter to find out whether or not the animal actually obtained from the consumption of a weighed ration of feeding stuffs the amount of heat indicated by these theoretical values. This was necessary because of the view held by some people that an animal possessed a certain mysterious power, called vital force or some similar name, which enabled it to defy the laws of physics and chemistry.

Armsby's Calorimeter.

The Pennsylvania calorimeter consists essentially of a metal chamber large enough to accommodate a steer. The chamber has double walls with a space between them. A complicated electrical arrangement enables the experimenters to maintain the inner and outer walls of the chamber at exactly the same temperature. This ensures that no heat can pass into or out of the chamber. The heat given out by the animal is removed from the inside of the chamber by a stream of cold water which circulates through a system of pipes somewhat re-

sembling a motor car radiator which is fixed under the roof of the chamber.

The volume of water flowing through this heat removing apparatus is measured from time to time, and its temperature is also taken very accurately every few minutes, both where it enters the chamber and where it comes out. The amount of water in kilograms flowing through the apparatus, multiplied by the difference of temperature between the entering and issuing water, gives the amount of heat in Calories removed from the calorimeter. This accounts for most but not all of the heat given out by the animal.

A current of air is drawn through the chamber to provide the animal with fresh air to breathe. This air is warmer when it comes out than when it enters, and consequently carries heat away with it. The amount of heat thus removed is calculated by multiplying the volume of air drawn through the chamber by its density, by the difference of temperature between the issuing and entering air and the specific heat of air.

A certain amount of heat is also carried out of the chamber in the issuing air in the form of latent heat of the water vapour exhaled by the animal. The weight of water vapour thus removed mutiplied by the latent heat of vaporisation of water gives the amount of heat removed from the chamber in this form. These three quantities of heat added together give the total amount of heat lost by the animal.

Heat Balance.

In the simplest possible case, in which the animal is consuming a maintenance ration on which he remains in exact carbon and nitrogen equilibrium, neither gaining nor losing protein or fat, this total amount of heat lost by the animal has been found to be exactly equal to the metabolisable energy of the ration.

Thus in the case of the experiment quoted in Chapter XVIII., p. 120, when the carbon and nitrogen balance indi-

cated exact equilibrium, the heat given out by the steer was exactly equal to the metabolisable energy of his ration of 14 lb. of meadow hay.

Metabolisable energy of ration of 14 lb. hay.	lb.	Calories.	Heat removed per day from calorimeter.	Calories.
Digestible protein	·75 × 2,133 =	1,609	In circulating water	8,934
,, fat ...	·14 × 4,000 =	560	In ventilating air ...	1,675
Digestible carbo-hydrates ...	3·60 × 1,707 =	6,146	In water vapour ...	1,291
Digestible fibre	2·10 × 1,707 =	3,585		
		11,900		11,900

It is practically impossible, however, to secure such ideally simple conditions as the above. There is always a gain or a loss of carbon and nitrogen during the experiment, and it is therefore impossible to strike a direct balance between the metabolisable energy of the ration and the heat given out by the animal If the animal loses carbon and nitrogen, some of his protein, or protein and fat must have been oxidised, and in being oxidised will have contributed to his heat production. If on the other hand, the animal has gained protein, or protein and fat, he has stored some of these constituents of his ration and if they have been stored they cannot have given out heat.

To enable the Pennsylvania investigators to cope with these difficulties, their calorimeter is fitted as a respiration chamber, so that, besides measuring the heat given out by the animal, they can also collect his excreta, dung, urine, carbon dioxide gas, and marsh gas, and thus determine also his carbon and nitrogen balance.

The following example taken from one of the Pennsylvania experiments will make clear the method of working and calculation.

Ration—6,988 gm. Timothy hay.
400 gm. linseed meal.

Carbon and nitrogen balance.

	gm.		gm.
Carbon in ration... ...	3,004·3	Nitrogen in ration... ...	78·3
Carbon in excreta—		Nitrogen in excreta—	
16,619 gm. dung 1,428·7 gm.		166·9 gm. dung 33·5 gm.	
4,375 gm. urine ... 124·2 „		4,375 gm. urine 32·4 „	
37 gm. scurf ... 8·0 „		37 gm. scurf ... 1·3 „	
4,730 gm. carbon dioxide 1,290·2 „			
142 gm. marsh gas ... 106·6 „			
Total carbon in excreta	2,957·7	Total nitrogen in excreta	67·2
Carbon stored in body	46·6	Nitrogen stored in body ...	11·1

Nitrogen is stored in the body as protein, and since the protein of a steer contains on the average 16·67 per cent. of nitrogen, the 11·1 gm. of nitrogen stored correspond to $11 \cdot 1 \times \frac{100}{16 \cdot 67} = 66 \cdot 6$ gm. protein. The protein of a steer contains 52·5 per cent. of carbon. Therefore 66·6 gm. of protein contain $66 \cdot 6 \times \frac{52 \cdot 5}{100} = 35 \cdot 0$ gm. of carbon.

The total storage of carbon in the experiment was 46·6 gm. Subtracting from this the 35·0 gm. of carbon stored as protein, the remainder, 46·6 — 35·0, or 11·6 gm. may be assumed to have been stored as fat. Fat contains 77 per cent. of carbon. Therefore 11·6 gm. of carbon correspond to $11 \cdot 6 \times \frac{100}{77}$ or 15·2 gm. fat. The balance experiment there-

fore shows that the steer stored per day 66·6 gm. of protein, and 15·2 gm. fat.

Now the heat of combustion of the protein of the steer is 5·7 Calories per gram, and as this protein is stored and not excreted, there is no deduction for combustible substances in the urine. The daily storage of heat in the form of protein therefore was 66·6 × 5·7 or 380 Calories.

Similarly the heat of combustion of the fat of a steer is 9·5 Calories per gram. Therefore the heat stored in 15·2 gm. fat is 15·2 × 9·5 or 144 Calories. The daily storage of heat in the form of fat is therefore 144 Calories.

The heat balance can now be made out as follows :—

Metabolisable energy of 6,988 gm. Timothy hay and 400 gm. linseed meal		12,101 Cal.
Heat evolved by animal as measured by the calorimeter	11,493 Cal.	
Heat stored as protein as measured by the nitrogen balance... ...	380 „	
Heat stored as fat as measured by the carbon balance	144 „	
Total heat evolved and stored ...		12,017 Cal.
Experimental error		84 Cal.

An errror of only 84 Calories in 12,000 corresponds to only ·7 per cent., which is an exceedingly small error for so complicated an experiment. Many experiments of this kind have been carried out in the Pennsylvania calorimeter. They show quite clearly that the heat producing power of the food eaten by an animal can be completely accounted for in the form of heat evolved by the animal, heat lost in the excreta and heat stored in the body, and that the animal therefore possesses no mysterious power of making heat out of nothing, thereby defying the laws of physics and chemistry. This conclusion is important for it proves that the laws of physics and chemistry apply to the animal body and the changes which take place inside it.

The Pennsylvania calorimeter has also been used to investigate another important and interesting question.

Net Energy.

Referring back to Chapter XIX. it will be seen that the fat producing power of a feeding stuff as measured by Kellner in terms of starch equivalent is always smaller than the heat producing power also expressed as starch. In the case of meadow hay, for example, the heat producing power or gross digestible energy per 100 lb. is 48·8 expressed as lb. of starch, whilst the fat producing power or starch equivalent is only 30·8 lb. starch. Taking the heat producing power as 100, the fat producing power is only 63. In other words, out of an amount of hay which could yield to the animal 100 Calories, only 63 Calories could be stored in the body as fat, the remaining 37 Calories being necessarily converted into heat. Kellner's explanation of this and similar facts was that the 37 calories were necessarily converted into heat in the process of digestion.

Thermic and Dynamic Energy.

This view was generally accepted, and a distinction was drawn by many writers between what was called the thermic energy of a feeding stuff, which is the proportion of the total energy necessarily transformed into heat in the process of digestion, and the dynamic energy, which is the proportion of the total energy which can be transformed into fat, as measured by Kellner, and by assumption into growth or milk or work. On this view, the total energy of meadow hay per 100 lb. is 48·8 lb. The dynamic energy 30·8 lb., and the thermic energy 48·8 — 30·8 or 18·0 lb. all expressed as starch equivalent.

Specific Dynamic Action.

Meantime other investigators, experimenting for the most part with dogs or human beings, had observed many facts which threw a new light on this question. It had been found that shortly after the taking of food there was always a marked rise in the rate of heat evolution as measured directly in the calorimeter or indirectly by observing the rate of

evolution of carbon dioxide in the breath. This was found to take place even when completely digested food was introduced through a tube into the stomach of a anaesthetised animal, in which case it could not be due to the work of digestion.

The suggestion was that it was due to the stimulating effect of the products of digestion on the rate of chemical change in the body. This increase of heat production following the consumption of any food substance was called its specific dynamic action.

The Pennsylvania investigators attacked this problem as follows:—in order to simplify the investigation they decided to make their observations on animals consuming less than a maintenance ration, so that there should be no need to carry out balance experiments in order to ascertain how much protein or fat was stored. If the ration is below maintenance requirements no storage can take place.

A steer was fed on a daily ration of 6·17 lb. of Timothy hay whose metabolisable energy had been found to be 935 Calories per lb. The ration therefore contained 6·17 × 935, or 5,768 Calories. The heat produced per day by the steer on this ration was then measured by the calorimeter and found to be 8,064 Calories. This is much greater than the heat provided by the ration. Consequently the animal must have oxidised some of his store of fat to provide the difference, which was 8,064 — 5,768, or 2,296 Calories. On this ration therefore the animal is compelled to provide per day 2,296 Calories from the oxidation of his own fat.

The ration was then increased to 10·21 lb. which contained 10·21 × 935, or 9,554 Calories, and the daily heat production again measured in the calorimeter, and found to be 9,812 Calories. On this increased ration therefore the animal was still compelled to provide 9,812 — 9,544, or 268 Calories per day by the oxidation of his own fat. Tabulating these figures:—

	Ration.	Calories provided by oxidation of body fat.
	6·17 lb. Timothy hay	2,296
	10·21 lb. ,, ,,	268
Difference	4·04 lb. Timothy hay	2,028 Calories.

The consumption of 4·04 lb. of Timothy hay reduced the amount of heat which the animal was compelled to provide from the oxidation of his own fat by 2,028 Calories. It may be assumed that the animal would oxidise of his own fat the minimum or net amount needed to provide energy for his vital functions. From this it follows that 4·04 lb. of Timothy hay contributed 2,028 Calories which the animal could use for performing his vital functions. Dividing by 4·04, 1 lb. of Timothy hay could evidently provide 2,028 ÷ 4·04, or 502 Calories which the animal could use for performing his vital functions.

The Timothy hay used in this investigation therefore provided per lb. 935 Calories of metabolisable energy of which only 502 Calories could be used for performing vital functions, the difference, 935 — 502, or 433 Calories being the proportion of the metabolisable energy which was necessarily transformed into heat in the process of digestion, either by the work of digestion as Kellner assumed, or by the specific dynamic action of the products of digestion of the hay according to later views, or partly by one method and partly by the other. Whichever explanation of the facts is adopted, the facts remain the same, namely that of the 935 Calories per lb. of metabolisable energy of Timothy hay, only 502 Calories can be used by a steer for physiological purposes, the balance of 433 Calories being necessarily transformed into heat which the steer cannot use for physiological purposes. Translating these facts into the older terms, the total heat producing value of Timothy hay is 935 Calories per lb. of which 502 Calories represent dynamic energy and 433 Calories thermic energy.

By many years of investigation on these lines, the Pennsylvania investigators were able to measure the metabolisable energy of a number of typical feeding stuffs, and the proportion of the metabolisable energy, which they call the net energy, which an animal can use for physiological purposes. From their results they were able to establish a connection between the total digestible nutrients of the several classes of feeding stuffs and their metabolisable and net energy values. This then enabled them to calculate the metabolisable and net energy values of many feeding stuffs and to compile the tables which are given in the appendix of Armsby's book—*The Nutrition of Farm Animals*, published by MacMillan, New York. Armsby's net energy values and Kellner's starch equivalents are essentially the same, both of them being intended to express the net productive values of feeding stuffs. They are, however, stated in different terms, Kellner's starch equivalents in terms of starch, and Armsby's net energy values in terms of Calories. They can, however, be converted quite readily into the same terms as follows:—

According to Kellner's results, 4 lb. of starch can produce in the body of an animal 1 lb. of fat, 1 lb. of average animal fat can produce on complete combustion 4,284 Calories. Therefore 1 lb. of starch can produce in the body 4,284 ÷ 4 or 1,071 Calories. If therefore Kellner's starch equivalents are multiplied by 1·071, which may be called the net energy value of 1 lb. of starch, they are converted into Calories of net energy, which if both Kellner's work and the Pennsylvania work are correct, should be approximately the same figures as the net energy values given in Armsby's book. The following table shows the comparison for a few feeding stuffs chosen at random from Kellner's and Armsby's tables: —

	Ration.	Calories provided by oxidation of body fat.
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	10·21 lb. ,, ,,	268
Difference	4·04 lb. Timothy hay	2,028 Calories.

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	Kellner's starch equivalent per 100 lb.	Therms per 100 lb.	Armsby's net energy Therms per 100 lb.	Difference as per cent. of Armsby's figures.
Red clover hay	31·9 × 1·071	= 34·16	38·68	− 12
Oat straw ...	17·0	18·21	34·81	− 48
Swedes ...	7·5	8·03	8·46	− 5
Oats	*59·7*	*63·94*	*67·56*	− 5
Barley ...	72·0	77·11	89·94	− 14
Maize... ...	81·5	87·28	84·00	+ 4
Wheat ..	71·3	76·36	91·66	− 15
Beans... ...	66·6	71·32	73·29	− 3

Out of the eight pairs of results taken at random, four pairs agree within five per cent., three other pairs within about 15 per cent., and there is only one serious discrepancy—oat straw. Taking into account the great complexity of the measurements in each case, the fact that Kellner and Armsby tried to arrive at the same result by entirely different methods, and that Kellner's results refer to feeding stuffs grown in Germany, whilst Armsby used American materials, the agreement between the two sets of results is quite as good as could be expected.

Armsby's and Kellner's work taken together make it quite certain that in designing rations for animals and in estimating the results which the rations should produce in the form of growth, fat, milk, or work, the fact must be recognised that only a certain proportion of the energy of any feeding stuff can be used by the animal for productive purposes, since a certain proportion is necessarily transformed into heat during the processes of digestion and absorption.

Exactly what these proportions are can only be accurately determined by further investigation, either on Kellner's or Armsby's lines, and such investigation with home grown feeding stuffs are badly needed. Meantime in the case of most feeding stuffs no serious error will result from using either Kellner's or Armsby's figures.

CHAPTER XXII.

MAINTENANCE REQUIREMENTS. FEEDING PIGS.

Maintenance and Production.

In computing rations for animals the object in view is to adjust the ration so that it may provide the material and energy required to enable the animals to produce the desired result, whether growth, fat, work, or milk. In order to achieve this object it must be remembered that part of the ration is required to maintain the vital functions of the animal—to provide for instance the energy necessary for maintaining circulation, respiration, and body temperature—and it is only the excess of the ration over these maintenance requirements which can contribute towards production.

In computing a ration it is therefore necessary to consider two points—how much is necessary for maintenance, and how much is necessary to attain the desired production of growth, fat, work, or milk.

Maintenance Requirement.

The first point to consider is the amount of the ration required for maintenance. The simplest method of ascertaining this is to keep the animal for several days in a calorimeter without food, measuring its heat production when asleep, and therefore resting. This method is not applicable in the case of cattle, sheep, or horses, which cannot be fasted long enough to ensure the completion of the digestion and absorption of the very large amounts of fibrous foods eaten by these animals. It has, however, been used with success at Cambridge in the case of the pig, in which animal, when full

grown, digestion and absorption are complete in about 96 hours after the last meal. In the Cambridge investigations an adult Large White hog weighing 300 lb. was put into the calorimeter immediately after a meal, and his rate of heat production recorded continuously for five days. During the day the rate of heat production varied greatly because the animal was restless. At night the hog slept from about 6 p.m. to about 6 a.m., and his rate of heat production fell continuously until about 4 a.m., when it usually became constant until he awoke. The rate of heat production was measured each night during the constant period about 4 a.m., and was found to decrease night by night up to the fourth night. The fifth night it remained at the same level as the fourth night, showing that the specific dynamic action of the last meal was exhausted, and that digestion and absorption were completed. The heat production on the fourth and fifth nights was approximately at the rate 2,300 Calories per day. During these observations the internal temperature of the calorimeter chamber was 20° C.

This figure of 2,300 Calories per day is the basal metabolism. The maintenance requirement must be greater by the energy required to make the daily movements of normal life. Recent measurements by an indirect method on many animals show the average daily movements use up as much as 1,000 Calories, which may easily rise to 2,000 Calories if management is not good—if, for instance, lack of trough space leads to scrambling for food. To assess the practical maintenance requirement it is necessary to adjust the basal metabolism for size as follows, and then to add an allowance for movement.

Maintenance in relation to size.

In rationing pigs it is necessary to know the requirements of animals of all sizes and ages, and the next point to investigate is the relation of requirements to size, or rather to weight, as weight is the most convenient way of measuring size. The German physiologist, Rubner, many years ago investigated this point by measuring the rate of heat production of

a series of dogs ranging in weight from 7 lb. to 60 lb., and comparing their rate of heat production with their weight, and with their surface. He found that the rate of heat production per lb. of the different animals was not constant, the smaller dogs giving off more heat per lb. than the larger ones. When, however, he calculated the area of the external surface of each animal, and divided its heat production by its surface area, he found that the rate of heat production per unit of surface was practically the same in every case.

The Surface Law.

He thus established the surface law, which is now generally accepted, to the effect that an animal's maintenance requirements are proportional to its surface area. Since all animals are approximately of the same density, and since volume × density = weight, the weight of an animal is proportional to its volume. Now volume is of three dimensions, length, breadth, and thickness, and surface is of two dimensions, length and breadth only. Surface is, therefore, proportional to the square of the cube root of volume, and since volume is directly proportional to weight, surface is also directly proportional to the square of the cube root of the weight.

Food requirements being proportional to surface, they must also be proportional to the square of the cube root of weight.

Taking as the starting point 2,300 Calories as the basal metabolism of a 300 lb. hog, the requirements of a hog of any other weight can be calculated thus. The cube root of 300 is 6·7, and 6·7 squared is 44·9. This figure 44·9 is the square of the cube root of 300, the weight in lb. of what may be called the standard hog. The next step is to write down in series the first eight numbers, to cube them, and to square them, thus—

Numbers	1	2	3	4	5	6	7	8
Squared	1	4	9	16	25	36	49	64
Cubed	1	8	27	64	125	216	343	512

The square of the cube root of the lower series of numbers can then be read off by inspection, and the basal metabolism according to Rubner's surface law calculated thus:—Hog weighing 512 lb. Square of cube root of 512 = 64. Basal metabolism $= 2300 \times \frac{64}{44 \cdot 9} = 3280$ Calories per day.

Hog weighing 343 lb. Square of cube root of 343 = 49. Basal metabolism $= 2300 \times \frac{49}{44 \cdot 9} = 2500$ Calories.

Hog weighing 216 lb. Square of cube root of 216 = 36. Basal metabolism $= 2300 \times \frac{36}{44 \cdot 9} = 1845$ Calories.

It is useless to calculate in this way basal metabolism for hogs weighing less than 200 lb., for the basal metabolism of young animals does not follow the surface law. The basal metabolism of a young Large White hog has been measured in the Cambridge calorimeter, and the results of these measurements are plotted in the maintenance requirement curve in diagram II. on page 163, an addition having been made for movement.

This curve shows the relation between the live-weight and maintenance requirement expressed in Calories. It refers to large white pigs kept at a temperature of about 20° C., which is the same as 68° F., the temperature of a fairly warm summer day. It is not likely that the maintenance requirement of other breeds of pigs would differ appreciably from the indications of this curve, at any rate in the case of animals weighing over 200 lb.

Effect of Temperature.

Variations in temperature, however, greatly increase basal metabolism. This question has been investigated at Cambridge by determining the basal metabolism of a hog as described above, when the internal temperature of the calorimeter chamber was kept at different temperatures ranging from 10° C. = 50° F to 23° C. = 73° F. It was found that the basal metabolism was constant between 20° C. and 23° C. As the temperature

fell below 20° C. the basal metabolism increased steadily at the rate of about 5 per cent of the basal metabolism at 20° C. per degree fall of temperature below 20° C. Thus when the temperature fell to 10° C., the basal metabolism of the 300 lb. hog rose from 2,300 Calories per day to $2{,}300 + 2{,}300 \times 5 \times 10 \div 100 = 3{,}450$ Calories per day. The higher temperature of 20° C. = 68° F. is the temperature of a fairly warm summer day. The lower 10° C. = 50° F. is the temperature of a fairly warm winter day. It looks, therefore, at first sight as if the change from summer conditions to winter conditions would make it necessary to increase the maintenance ration by something of the order of 50 per cent.

Body Temperature.

Before accepting such a drastic conclusion, however, it will be wise to enquire rather more fully into the method by which an animal maintains its body temperature constant in spite of variations in the temperature to which it is exposed. The rate at which heat is lost from the surface of an animal's body depends on the difference of temperature between the animal's skin and the air which surrounds it. The temperature of the air is, of course, beyond the animal's control. He can, however, control the temperature of his skin by altering the course of his blood supply.

If the surrounding air is cold he diverts the blood supply from his skin to his internal organs. His skin, deprived of blood to warm it, becomes cold, which decreases the difference of temperature between his skin and the surrounding air, and minimises the rate of loss of heat from his body surface. If, in spite of this reduction of heat lost from the skin, more heat is lost than is provided by the normal metabolic processes, involuntary muscular movement, *i.e.* shivering, takes place in an attempt to provide for this extra heat loss.

If, on the other hand, the surrounding air is warm, the animal sends a full blood supply through his skin, which is thus kept warm and loses heat rapidly. If

the air is so warm that even the fullest possible blood supply will not keep his skin warmer than the air, so that the air fails to cool his skin, then as a last resort he sets his sweat glands to work and pours out sweat on to his body surface. This evaporates into the air, and cools the skin by absorbing from it the necessary latent heat of vaporisation.

Critical Temperature.

When the temperature of the surrounding air falls below a certain temperature, diversion of the blood supply from the skin fails to keep the skin cold enough to lower the rate of heat loss sufficiently to enable the animal to maintain his internal body temperature constant. Below this temperature, which is called the critical temperature, the animal is compelled to oxidise more food, or failing food, more of his own fat, and consequently his basal metabolism increases continuously as the temperature falls. The critical temperature in the case of the pig is about 20° C. If a pig is kept at temperatures below 20° C., his basal metabolism increases at the rate of about 5 per cent. for each degree C. fall in temperature as stated above.

Practical Conclusions.

But pigs are not in practice kept on maintenance rations. Every one expects his pigs to increase in live weight at the rate of at least 1 lb. per day. This increase in weight consists of water, protein, fat, and ash, and its average composition has been found by comparative slaughter tests—see Chapter XVIII., page 117. From the average composition it appears that 1 lb. of increased live weight made by a pig contains 2,700 Calories.

To store 2,700 Calories in his body the pig's ration must supply 2,700 Calories of net energy over and above his maintenance ration. Armsby estimates that 100 lb. of barley meal can supply to a pig 106 therms of net energy. This is equivalent to 1,060 Calories per lb. Consequently 2,700 Calories of net energy corresponds to a ration of 2,700 ÷ 1,060 = 2.5 lb.

A 300 lb. hog would, therefore, in practice get a ration of at least 2·5 lb. of barley meal or its equivalent over and above its maintenance ration. The maintenance ration of 3,200 Calories would also correspond to about 3 lb. of barley meal. The total ration would therefore be $5\frac{1}{2}$ lb.

Now the metabolisable energy of barley meal is about 1,460 Calories per lb., so that each lb. consumed produces 1,460 − 1,060 = 400 Calories of heat which cannot be used for the production of increased body weight. Consequently, the ration of $5\frac{1}{2}$ lb. would produce $5\frac{1}{2} \times 400 = 2{,}200$ Calories of heat, which, although not available for production of increase, would serve to maintain the body temperature, and prevent the oxidation of food for this purpose.

The maintenance ration of the 300 lb. hog at 20° C. was found to be 3,200 Calories which, as the temperature fell, increased by 5 per cent., or 160 Calories per degree Centigrade. The waste heat or thermic energy amounting to 2,200 Calories would therefore serve to maintain the body temperature during a fall in temperature of $2{,}200 \div 160 = 14°$ C.

On an average practical ration, therefore, there would be no need for increased oxidation of food for maintenance of body temperature unless the temperature of the surrounding air fell below $20 - 14 = 6°$ C. or 43° F., the temperature of a cold winter day. In other words, the heat necessarily produced during the processes of digestion and absorption of average rations may be regarded as lowering the critical point from about 20° C. to about 6° C. or 43° F. Consequently, it is only in very cold weather in the winter that the pig is compelled to oxidise an increased proportion of his ration in order to maintain his body temperature. This is not, therefore, a very serious matter, for except during prolonged frosts there are not many days in the year when the temperature of the air of a pig stye would fall seriously below 43° F. This would not be so with pigs kept in the open air, but in their case the cost of the extra food required would be balanced by the decreased cost of housing.

Maintenance of Young Animals.

In calculating the basal metabolism of the pig by the surface law above, it was stated that this law did not hold for young growing animals. The maintenance requirements of such animals have been studied at Cambridge. A young Large White hog was observed in the calorimeter at regular intervals from the time when his age was 60 days and his live weight 28 lb., until he was 365 days old and weighed 300 lb. The results of these observations are included in the maintenance requirement curve of diagram II. on p. 163.

From this curve it is possible to read off at once the maintenance requirement of a pig of any weight from 28 lb. to 300 lb. in terms of Calories of net energy.

Growth Rate.

No one, however, wishes to keep his pigs on a mere maintenance ration—he wishes them to grow and to increase in weight. A young pig at birth weighs on the average about $2\frac{1}{2}$ lb. For the first ten days of his life he puts on about $\frac{1}{4}$ lb. increased weight per day, doubling his weight, therefore, in ten days. From this date his rate of growth soon increases to about $\frac{1}{2}$ lb. per day. When he weighs 80 to 100 lb. his growth rate is about 1 lb. per day, increasing as he grows larger to $1\frac{1}{2}$ or even 2 lb. per day. Under good conditions a pig may reach a weight of 200 lb. at 7 months, which means an average daily growth rate of nearly 1 lb. per day. In exceptional cases, where pigs have been fed all their life for exhibition, live weights of 300 lb. have been reached in six months, but this is not an economic practice for commercial purposes, as it involves the use of very digestible and appetising foods such as separated or even condensed or new milk.

The comparative slaughter method introduced by Laws and Gilbert and used subsequently by many investigators, especially in Germany and in America, has provided important information as to the composition of live weight increase in the case of pigs at different ages. Live weight increase of very young pigs is mainly composed of water and contains

little protein and only a trace of fat. As the young pig grows each successive lb. of increase contains more fat and less water and consequently requires more food for its production. This is shown in the dotted curve in diagram II. which gives the calorie value per lb. of increase at various live-weights.

Diagram II. on p. 163 also includes a curve, showing the daily requirement for protein of pigs of varying weight. This curve is based on the standards given by Kellner, which in turn were based on the results of a number of cooperative feeding trials, carried out at a number of stations in Germany. The curve probably errs on the side of excess of protein, but more reliable information is not available.

Diagram II. and Table I. contain between them the necessary information for the computation of rations for pigs at any weight. The method of using them will be made clear by a few instances. To compute a ration for a pig weighing 50 lb. The maintenance requirement curve in Diagram II. shows that the maintenance ration of a 50 lb. pig is 1,500 Calories of net energy. Such a pig might grow at the rate of about $\frac{1}{2}$ lb. per day. At this age and weight 1 lb. of live weight increase contains about 700 Calories (see dotted line). The full ration to produce $\frac{1}{2}$ lb. increase per day would then be $1{,}300 + 350 = 1{,}650$ Calories. If this is provided in the form of fine middlings (see Table I.), $1{,}650 \div 1{,}070$ or $1\frac{1}{2}$ lb. will be required. $1\frac{1}{2}$ lb. of fine middlings (see Table I.) contain $1\frac{1}{2} \times 13{\cdot}2 \div 100 = {\cdot}2$ lb. of digestible protein. The protein curve on diagram I. indicates that a 50 lb. pig requires ·3 lb. The middlings ration, therefore, does not supply quite enough. To correct this, part of the middlings must be replaced by a feeding stuff richer in protein. The most popular food for this purpose is fish meal, which should be white fish meal containing 50 per cent. of protein, and not more than 5 per cent. of oil and 1 per cent. of salt. The deficiency of protein is only ·1 lb. To supply this amount only, ·2 lb. would be required. The ration would then be $1\frac{1}{2}$ lb. of fine

middlings and ·2 lb. of fish meal. The easiest way to make up such a ration would be to mix together very thoroughly 150 lb. of middlings and 20 lb. of fish meal, and to use just under 2 lb. of the mixture. For a 50 lb. pig this should suffice to produce a daily gain in live weight of about ½ lb. To make sure that the pig does not suffer from deficiency of vitamines he should be given access to a small amount of some kind of green food every day.

As a rule, it is not advisable to use a ration consisting so exclusively of one constituent as the above. A mixed ration is generally advisable because it is more palatable, and because the proteins of the various constituents tend to balance one another. The following example will show how to work out a mixed ration, again for a 50 lb. pig.

Suppose that prices indicate that barley meal, middlings and coconut cake meal are the cheapest foods suitable for young pigs. Then a mixture of these materials in the proportions of 2 : 2 : 1 will contain 11·1 per cent. of digestible protein and 1,082 Calories of net energy per lb. Thus :—

	Protein per cent.	Calories per lb.
2 parts barley	6·5 × 2 = 13·0	1060 × 2 = 2120
2 parts middlings	13·2 × 2 = 26·4	1070 × 2 = 2140
1 part coconut	16·2 × 1 = 16·2	1150 × 1 = 1150
5 parts mixture	55·6	5410
1 part mixture	11·1	1082

To produce 1 lb. daily gain, 1,650 Calories are required. Since the mixture contains 1,082 Calories per lb. 1,650 ÷ 1,082 or 1½ lb. will be required. This will supply 1½ × 11·1 ÷ 100 = ·17 lb. digestible protein, which is ·13 lb. below the normal requirement. To supply this ·26 lb. of 50 per cent. fish meal is necessary. The ration would then be 1½ lb. mixture and ·26 lb. fish meal. The easiest way to make up such a ration would be to mix together intimately 6 lb. of the mixture and 1 lb. of fish meal, and to use just under 2 lb. per

head per day. An alternative, and perhaps easier way, would be to mix together 40 lb. each of barley meal and middlings, 20 lb. of coconut cake meal, and 16 lb. of fish meal, which would give exactly the same result.

To compute a ration for a pig weighing 150 lb. At this weight the pig will be approaching the weight at which pigs nowadays are slaughtered for bacon. It is therefore advisable to avoid feeding stuffs such as fish meal, maize, linseed, or oily foods which are reputed to produce soft bacon. Let us suppose that questions of price and supplies indicate the use of barley meal, coarse middlings, and potatoes.

A mixture of these materials in the proportion of 3 : 1 : 4, works out as follows :—

	Protein per cent.	Calories per lb.
3 parts barley	6·5 × 3 = 19·5	1060 × 3 = 3180
1 part middlings	13·8 × 1 = 13·8	1040 × 1 = 1040
4 parts potatoes	1·1 × 4 = 4·4	250 × 4 = 1000
8 parts mixture	37·7	5220
1 part mixture	4·7	452

At this weight a pig should be capable of putting on 1½ lb. increase per day, containing per lb. 1,350 Calories, or per 1½ lb. 2,025 Calories. The maintenance requirement is 3,300 Calories. The total ration required to produce 1½ lb. increase per day is therefore 5,325 Calories. This would require 5,325 ÷ 452 or 11¾ lb., which would include 5¾ lb. of potatoes, 4½ lb. of barley, and 1½ lb. of middlings. This ration would contain ·55 lb. of digestible protein, which is about the normal requirement—see protein requirement curve. The easiest way to give such a ration would be to make a mixture of 3 parts of barley meal and 1 part of middlings, to weigh out of this the day's allowance at the rate of 6 lb. per pig, and to stir it into an equal weight of cooked potatoes. In all cases it is wise to decrease the ration if it is not cleared up at once, and to increase it if the pig will eat more.

It will be noticed that no example is given of calculating rations for very small pigs. The reason is that there is practically no information as to the maintenance ration of pigs below about 30 lb., and that in the absence of accurate information, the feeding of such very young animals must for the present remain an art which must be acquired by practical experience rather than a science based on proved principles. Certain points are, however, well known. Young pigs from weaning up to 50 lb. weight require very digestible foods containing little fibre—such, for instance, as fine middlings, pea meal, maize gluten feed or meal, maize meal, or coconut cake, of which a mixture is better than any single food. They require a good supply of protein, which may be given as fish meal, meat meal, dried blood or dried yeast, of which not more than 2 oz. per head per day should be used. It is most advantageous to mix these foods with skim milk or whey instead of water. Young pigs should also have access to green stuff to supply vitamines.

MAINTENANCE REQUIREMENTS. FEEDING PIGS.

Table I and Diagram II. overleaf.

Showing Composition of Foods suitable for pigs and curves for maintenance and protein requirements.

TABLE I.—FEEDING STUFFS FOR PIGS.

	Dry Matter per cent.	Digestible Protein per cent.	Net Energy Calories per lb.	Nutritive Ratio 1 :	Manurial Value per ton. Shillings.	Remarks. Effect on Bacon.
Barley	85	6·5	1060	10	12	Good
Maize	87	7·1	1200	11	13	Bad
Wheat	87	10·2	1090	7	15	Good
Beans	86	20·1	1000	2	32	,,
Peas	86	19·4	1000	3	28	,,
Middlings—Fine ...	87	13·2	1070	5	22	,,
,, —Coarse	87	13·8	1040	4	22	,,
Pollards	87	11·6	1040	5	27	,,
Coconut Cake ...	89	16·2	1150	4	30	Bad
Palm Kernel Cake Meal	89	17·1	1100	4	23	,,
Palm Kernel Meal extracted... ...	89	17·1	1050	4	24	,,
Maize Gluten Feed	90	20·0	1100	3	27	—
,, ,, Meal	91	30·6	1180	2	40	—
Dried Blood ...	86	72·7	1050	·1	80	—
Meat Meal	93	39·2	1100	1	54	—
Flesh Meal	89	67·2	1100	·5	75	—
Fish Meal	87	50·0	820	·2	86	Bad
Dried Yeast ...	96	41·6	980	·7	55	—
Potatoes	22	1·1	250	16	4	Good
Pasture	25	1·9	120	6	—	—
Marrow Stem Kale	15	1·8	150	5	4	—
Tares	17	2·2	133	4	5	—
Swedes	11·5	17·0	135	7	2	—
Mangolds	12	·4	136	13	3	—
Skim Milk	9	3·3	140	·2	—	Good

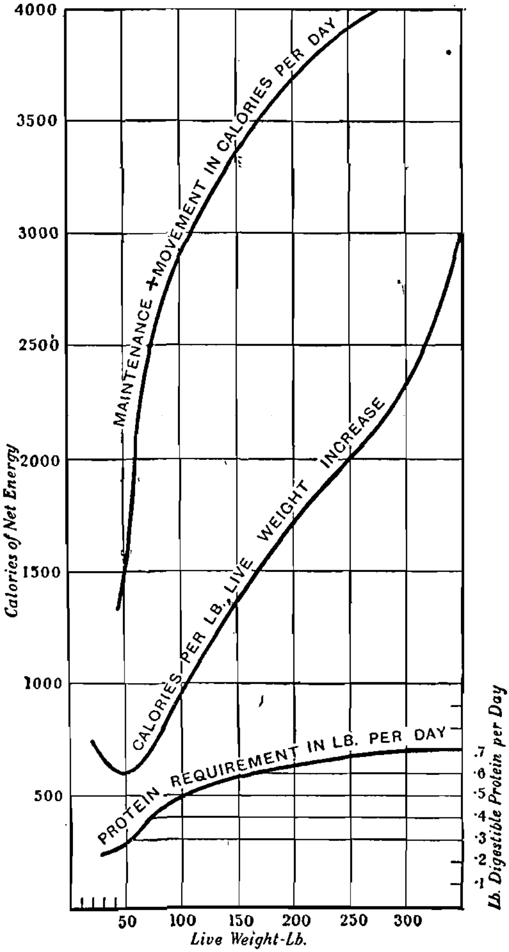
4000
3500
3000
2500
2000
1500
1000
500
Calories of Net Energy
MAINTENANCE + MOVEMENT IN CALORIES PER DAY
CALORIES PER LB. LIVE WEIGHT INCREASE
PROTEIN REQUIREMENT IN LB. PER DAY
·7
·6
·5
·4
·3
·2
·1
Lb. Digestible Protein per Day
50
100
150
200
250
300
Live Weight-Lb.

DIAGRAM II.

CHAPTER XXIII.

RATIONS FOR WINTER BEEF PRODUCTION.

Maintenance Requirements of Steers.

The maintenance requirements of cattle have been determined by many investigators. Kellner, by the balance experiment method, arrived at the conclusion that the maintenance ration of a 1,000 lb. steer should provide 6 lb. of starch equivalent which should include at least ·5 lb. or, preferably, ·7 lb. of digestible protein (see page 121).

Armsby used a different method, and expressed his result in terms of net energy. Referring back to the experiment quoted in Chapter XXI., p. 146, by which Armsby found the net energy of Timothy hay to be 502 Cal. per lb., it will be seen that the consumption of 10·21 lb. per day of this hay still failed to provide for maintenance by 268 Cal. per day of net energy, This amount of net energy could have been supplied by adding to the ration 268 ÷ 502 or ·53 lb. of the hay. The maintenance ration would, therefore, be 10·21 + ·53 or 10·74 lb. of hay, which at 502 Cal. of net energy per lb. = 10·74 × 502, or 5,391 Cal. of net energy. Adjusting this by the surface law to an animal of 1,000 lb. live weight, the maintenance ration of a 1,000 lb. steer was found to be approximately 6,000 Cal. per day, which was supplied by 12 lb. of hay. Armsby's experiments were carried out in his calorimeter, the internal temperature of which was 18° C. The maintenance ration of a 1,000 lb.

steer at 18° C. is, therefore, 12 lb. of Timothy hay or 6,000 Calories of net energy.

Effect of Temperature.

Now the Timothy hay, see p. 145, was found to supply per lb. 935 Cal. of metabolisable energy: 12 lb. would, therefore, supply 12 × 935, or 11,220 Cal. of metabolisable energy. The ration of 12 lb. would, therefore, supply besides the 6,000 Cal. of net energy required for maintenance at 18° C., 11,220 — 6,000, or 5,220 Cal. of thermic energy which must be transformed into heat in the processes of digestion and absorption, and could be used if required for maintenance of body temperature.

There are no measurements of the effect of temperature on the maintenance requirements of steers comparable with the Cambridge measurements in the case of the pig. Assuming, however, that the effect of fall of temperature is the same in the steer as it is in the pig, namely 5 per cent. per degree C., and assuming that 18° C. is not above the critical temperature, then the increased requiremement per degree below 18° C. would be 5 per cent. of 6,000 Cal., or 300 Cal. per degree. The hay ration provides 5,220 Cal. of thermic energy, which corresponds to the increased demands due to a fall of 5,220 ÷ 300, or 17° C. A steer on a maintenance ration of hay would, therefore, not require to oxidise food or tissues for the maintenance of his body temperature unless the surrounding temperature should fall below 18 — 17 or 1° C., or practically below the freezing point.

Maintenance Requirements in Terms of Hay.

The maintenance ration of a 1,000 lb. steer may, therefore, be taken as about 14 lb. of good hay, varying a few pounds more or less, according to the quality of the hay and the individuality of the animal. This figure has been repeatedly confirmed by British experimenters. It agrees fairly well with Armsby's figure of 6,000 Calories of net energy, and with Kellner's figure of 6 lb. of starch equivalent, thus:—The starch equivalent of 100 lb. of good hay is 40;

of 1 lb., therefore, ·4, and of 14 lb. 5·6 lb. starch equivalent. 5·6 lb. starch equivalent provides 5·6 × 1,071 = 6,000 Calories of net energy.

Good hay usually contains 5 to 6 per cent. of digestible protein. Consequently 14 lb. would contain at least ·8 lb., which is above the necessary ·5 lb. quoted by Kellner and by Armsby as the protein maintenance requirement per day of a 1,000 lb. steer.

Adjustment by Surface Law.

Adopting 14 lb. of good hay as the maintenance ration of a 1,000 lb. steer, the surface law can be used to calculate the maintenance ration in terms of hay for animals of varying weight, and the results can be plotted on a curve, as shown in Diagram III., p. 175. From this curve the maintenance requirement in terms of hay for cattle of varying weight can be found by inspection with a minimum of trouble.

It should be noted that the curve almost certainly fails to give correct results in the case of young animals whose maintenance requirements are probably much in excess of the indications of the surface law. No exact measurements of this excess are available in the case of cattle.

Composition of Live Weight Increase

Having determined the maintenance ration of cattle of varying weight, the next step is to compute the productive part of the ration. The main point to bear in mind in this computation is that there should be a direct relation between the amount of the productive ration and the result which it is designed to produce. In feeding cattle, except milch cows, the desired result is a gain in live weight. Gains in live weight consist of water, protein, fat, and ash. In young animals water, protein, and ash form a considerable proportion of the gain: as the animals grow older the proportion of fat in the gain increases at the expense of the other constituents, until in the case of an adult very fat animal, any gain in live weight which may be produced will consist almost entirely of fat.

Live Weight *Increase* Expressed in Calories.

In measuring the gain for the present purpose it is convenient to transform the protein and fat into Calories so that the whole gain may be expressed by one figure. In this way Armsby, from consideration of all the recorded experiments on the chemical composition of gains in live weight, both by the comparative slaughter method and by the balance method, concludes that 1 lb. of live weight increase in a young animal contains 2,500 Calories, in an average animal 3,250 Calories, and in an adult animal 4,000 Calories.

Taking first the average animal, for instance a two-year-old steer in store condition. In feeding such an animal for beef production most graziers would aim at a daily increase of 2 lb. live weight per day. This would contain 2 × 3,250 = 6,500 Calories, to produce which at least 6,500 Calories of net *energy, or 6,500 ÷ 1,071 = 6 lb. of starch equivalent would* be required. If the animal weighs 1,000 lb., or about 9 cwt., the ration would be:—

For maintenance, 14 lb. hay.

For production of 2 lb. per day live weight increase, 6 lb. starch equivalent.

The ration should include for maintenance ·6 — ·8 lb. of digestible protein.

For production, or rather to provide the material for making extra digestive juices and the small amount of protein included in the increase, and to increase the palatability of the ration, ·6 — ·8 lb. digestible protein, a total of, say, 1·5 lb. of digestible protein.

In the simplest case, the maintenance part of the ration might be given in the form of 14 lb. of good hay. Usually the productive part of the ration will consist for the most part of roots: swedes, for instance. Now the starch equivalent of 100 lb. of swedes is 7·3 lb. The weight of swedes required to supply the necessary 6 lb. of starch equivalent will, therefore, be *100 × 6 ÷ 7·3 = 82 lb. of swedes.*

The whole ration should now be checked to see if it contains enough digestible protein equivalent, thus:—

14 lb. hay contains ...	... ·8 lb.	digestible protein
82 lb. swedes contain $\frac{82}{100} \times \cdot 7 =$	·57	,, ,, ,,
Total ration contains ...	1·37	
It should contain about ...	1·5	

The deficiency of protein should be made good by replacing part of the swedes by a protein-rich food. For this purpose it is usual to make use of some kind of oil-seed residue, the most popular being a mixture of linseed and cotton seed cakes. Linseed cake contains 25 per cent., cotton seed cake 18 per cent. of digestible protein. A half and half mixture would, therefore, contain 21·5 per cent., and 1 lb. of the mixture would certainly make up the protein deficiency. It would also improve the palatability of the ration as a whole, and prevent any tendency to scouring from the consumption of a heavy root ration. The starch equivalent of linseed cake is 74, of cotton cake 42; the average starch equivalent of the mixture is, therefore, 58, and of 1 lb. of the mixture ·58 lb. The total starch equivalent required above maintenance is 6 lb. If ·58 lb. of this is supplied by the cake mixture, $6 - \cdot 58 = 5 \cdot 4$ lb. must be supplied as roots, and for this purpose $5 \cdot 4 \times 100 \div 7 \cdot 3$, or 75 lb. will be required.

The final ration will now read:—

For maintenance 14 lb. hay supplying ...	... 6 lb. st. equiv. and	·8 lb. dig. prot.
For production 1 lb. cake supplying ...	... ·58 lb. ,, ,,	·21 ,, ,, ,,
75 lb. swedes supplying ...	5·4 lb. ,, ,,	·5 ,, ,, ,,
	11·98	1·51

Such a ration will be palatable and, consequently, readily eaten; it will contain enough coarse fodder to keep the

animals comfortably full, and it will provide enough starch equivalent or net energy in excess of maintenance requirements to enable the animals to store 6,500 Cals. per day as protein and fat, which corresponds to a gain per day in a store animal of about 2 lb. live weight. Such a ration is, however, not within the reach of every grazier. On many farms it would be impossible to spare 14 lb. of good hay per day for every steer which the farmer desires to fatten, and, such a practice would leave a surplus of straw. In this case the hay might be replaced, for instance, by barley straw.

Barley straw contains 23 lb. of starch equivalent per 100 lb., which corresponds to 23 × 1,071 ÷ 100, or 236 Calories of net energy per lb.

The weight of barley straw required to provide the 6,000 Calories necessary for the maintenance of a 1,000 lb. steer is 6,000 ÷ 236 or 25 lb. Barley straw contains only about ·6 per cent. of digestible protein equivalent, and 25 lb. would, therefore, contain only ·1 lb., which is far short of the maintenance requirement of ·7 lb. The deficiency can, however, be made up by increasing the cake in the productive part of the ration. This will, as before, consist chiefly of roots, for instance, yellow globe mangolds.

The starch equivalent of yellow globe mangolds is 5·5 lb. starch equivalent per 100 lb. To provide the 6 lb. starch equivalent required to produce 2 lb. per day live weight increase 100 × ·6 ÷ 5·5, or 110 lb. would be required, and this quantity would contain only ·8 lb. of digestible protein equivalent. The ration, so far, would be—

25 lb. barley straw containing	6 lb. st. equiv. and	·1 lb. dig. prot.
110 lb. mangolds containing	6 ,, ,, ,, ,,	·5 lb. ,, ,,
Total	12	·6

This shows a deficiency of at least ·9 lb. of digestible protein, which can most readily be made up as before by including some kind of oil-seed cake or meal in the ration in place of part of the roots. It will be advisable to include some cotton cake to neutralise the laxative action of the very heavy root ration, and since the protein is very deficient, to mix with the cotton cake some kind of cake very rich in protein, for instance ground nut cake, which contains 42 per cent. of digestible protein. Cotton cake containing 18 per cent., the average content of the mixture will be 30 per cent., and 3 lb. will contain enough protein to correct the deficiency.

The ration will now read:—

For maintenance—			
25 lb. barley straw	= 6 lb. st. equiv. and	·1 lb. dig. protein.	
For production—			
80 lb. *mangolds*	= 4·5 „ „ „	·3 lb. „ „	
3 lb. cake	= 1·7 „ „ „	·9 lb. „ „	
	12·2 lb.	1·3 lb.	

This ration would be too bulky. In practice the animals would probably be given 30 lb. of long straw per head per day. They would pick out the leafy parts which are more palatable and digestible, and the remainder would be thrown under them for litter.

Another variation would be necessary when as in some seasons the root crop partially fails, and a heavy root ration is not available. A common practice under such conditions is to persuade the animals to fill themselves with straw. This is done by chaffing the straw and mixing it with pulped roots the day before it is to be used, or by moistening it with treacle dissolved in water. Either treatment softens the straw and makes it more palatable, but neither increases its nutritive value. By adopting some such treatment 9 cwt. steers will consume some such ration as the following:—

20 lb. barley straw	= 5 lb. st. equiv. and	·1 lb. dig. protein.	
20 lb. mangolds	= 1 lb. ,, ,, ,,	·1 lb. ,, ,,	
4 lb. cake	= $2\frac{1}{2}$lb. ,, ,, ,,	1·2 lb. ,, ,,	
	$8\frac{1}{2}$lb.	1·4 lb.	

Such a ration contains practically enough protein, but it is deficient in starch equivalent. It supplies only $8\frac{1}{2} - 6$ or $2\frac{1}{2}$ lb. starch equivalent above maintenance, and the live weight increase which it may be expected to produce will consequently be only 1 lb. per head per day approximately. If by making it palatable animals are tempted to eat more straw than will suffice for their maintenance requirements, they will not be able to eat enough of the more productive constituents of their ration to provide for a normal rate of increase because the capacity of their paunches is limited. If on the other hand they are given a larger ration of more palatable and productive foods, such for instance as cake, they will reject a proportion of the straw which is offered to them.

In feeding younger animals, for instance 10 months old steers intended for baby beef, it must be recognised that any increase they make will contain more water and less fat and that it will therefore require less starch equivalent or net energy per lb. to produce. Armsby estimates that the live weight increase of such animals contains per lb. only 2,500 Calories. A daily increase of 2 lb. live weight would therefore require 5,000 Calories of net energy which corresponds to 5,000 ÷ 1,071 or 4·7 lb. of starch equivalent. In designing rations for such animals, weighing say 6 cwt. live weight, the procedure is as follows:—Inspection of the maintenance requirement curve on p. 175 shows that the maintenance requirement of 6 cwt. cattle is $4\frac{1}{2}$ lb. starch equivalent. Let us assume that the home grown fodders available are good hay, swedes, and beans which can be ground into meal.

The maintenance requirement will be satisfied by $4\frac{1}{2}$ lb. starch equivalent or 10 lb. of good hay.

To provide for 2 lb. daily increase 4·7 lb. of starch equivalent will be required. This is contained in $100 \times \frac{4 \cdot 7}{7 \cdot 3}$ or 65 lb. of swedes. This would be too high a root ration for animals of this size and the ration would also be deficient in protein:—

For maintenance—			
10 lb. hay	containing	4·5 lb. st. equiv. and	·5 lb. dig. protein.
For production—			
65 lb. swedes	,,	4·7 lb. ,, ,,	·4 lb. ,, ,,
		9·2 lb.	·9 lb.

The protein requirement of a fatting animal of 6 cwt. is 1·4 lb. The deficiency is therefore ·5 lb. Bean meal, the other available home grown fodder, contains 20 per cent. of digestible protein, and 2½ lb. would therefore make up the deficiency. But experience shows that 2½ lb. of bean meal would be too much for such animals, as it is inclined to cause constipation. It would be wise to buy, for instance, linseed cake to mix with it. A half and half mixture of bean meal and linseed cake would contain 22½ per cent. of digestible protein and its starch equivalent would be 70 lb. starch equivalent per 100 lb. 2½ lb. of the mixture would make up the protein deficiency and would supply 1·9 lb. of starch equivalent. This would leave 2·8 lb. of starch equivalent to be supplied as swedes, which would be contained in 40 lb. The ration would therefore be:—

For maintenance—			
10 lb. hay	containing	4·5 lb. st. equiv. and	·5 lb. dig. protein.
40 lb. swedes	,,	2·8 lb. ,, ,,	·3 lb. ,, ,,
2½ lb. cake and meal	,,	1·9 lb. ,, ,,	·6 lb. ,, ,,
		9·2 lb.	1·4 lb.

Such a ration would produce 2 lb. per head per day live weight increase. It illustrates the fact that a given amount of food produces more live weight increase in a young animal.

Live weight increase in older animals, especially when they

are in good condition, is much more expensive to produce. Armsby estimates that on account of its small content of water and high content of fat, the live weight increase in a three year old steer in good condition weighing 13 cwt. contains 4,000 Calories per lb. It would require therefore 4,000 ÷ 1,071 = 3·7 lb. of starch equivalent to produce 1 lb. of live weight increase in such an animal.

A typical ration worked out on this basis to give 2 lb. daily increase would be:—

For maintenance—						
22 lb. barley straw	containing	5 lb.	st. equiv.	and	·1 lb.	dig. protein.
For production—						
75 lb. swedes	,,	5·4 lb.	,,	,,	·5 lb.	,,
3 lb. ground nut cake	,,	2·2 lb.	,,	,,	1·3 lb.	,,
		12·6 lb.			1·9 lb.	

Such a ration would contain about 30 lb. of dry matter which is 2 or 3 lb. more than most 13 cwt. animals would eat. Consequently they would probably reject some of their straw, which is the least palatable constituent of their ration, and in this case a corresponding amount of the more expensive roots and cake would be used for maintenance. Consequently less would be left for production and the live weight increase would fall correspondingly short of 2 lb. per day. To maintain the rate of increase of such animals it would be necessary to reduce the straw and to give more cake, an expensive practice only justifiable in the case of animals in preparation for the show yard.

Summarising this chapter, the method of rationing fattening cattle in the winter is as follows:—

Ascertain the weight of the animals.

From the maintenance curve find their maintenance requirements.

Calculate the weight of coarse fodder required to provide for maintenance.

Decide what result you wish to produce in terms of live weight increase per day.

TABLE II.—FEEDING STUFFS FOR STORE AND FAT CATTLE AND SHEEP.

	Dry Matter per cent.	Digestible Protein Equivalent per cent.	Starch Equivalent per 100 lb.	Nutritive Ratio 1:	Manurial Value per ton (1923) shillings.	Remarks.
Coarse fodders—						
Meadow Hay—very good ...	84	9·2	48	5	—	
Meadow Hay—good	86	5·4	37	8	—	
Meadow Hay—poor	86	3·4	24	11	—	
Seeds Hay—average	86	6·2	30	6	—	
Oat Straw ...	86	1·0	23	39	—	
Barley Straw ...	86	0·8	24	52	—	
Succulents—						
Swedes	11·5	·7	7·3	7	—	
Mangolds—white-fleshed	10·7	·4	5·5	11	—	
Mangolds—red or yellow fleshed...	13·1	·4	6·8	14	—	
Turnips	8·5	·4	4·4	9	—	
Silage—average...	30	2·8	12	5	—	
Concentrates—						
Cotton Cake, Bombay ...	88	16·0	40	2	34	
Cotton Cake, Decorticated ...	90	35·0	71	1	54	
Ground Nut Cake, Undecorticated	90	28·0	57	1	35	
Ground Nut Cake, Decorticated ...	90	42·0	73	1	55	
Linseed Cake ...	89	25·0	74	2	38	
Maize	87	7·1	81	11	13	
Maize Germ Meal	89	10·4	85	7	20	
Palm Kernel Cake	89	17·1	75	4	23	
Palm Kernel Meal extracted	90	17·1	71	3	24	
Soya Bean Cake...	86	38·0	69		53	
Pasture—						
Very Good ...	25					Variation in crop per sq. yd.
Average	25	5	17	4	—	
Poor	25					

RATIONS FOR CATTLE—PER DAY.

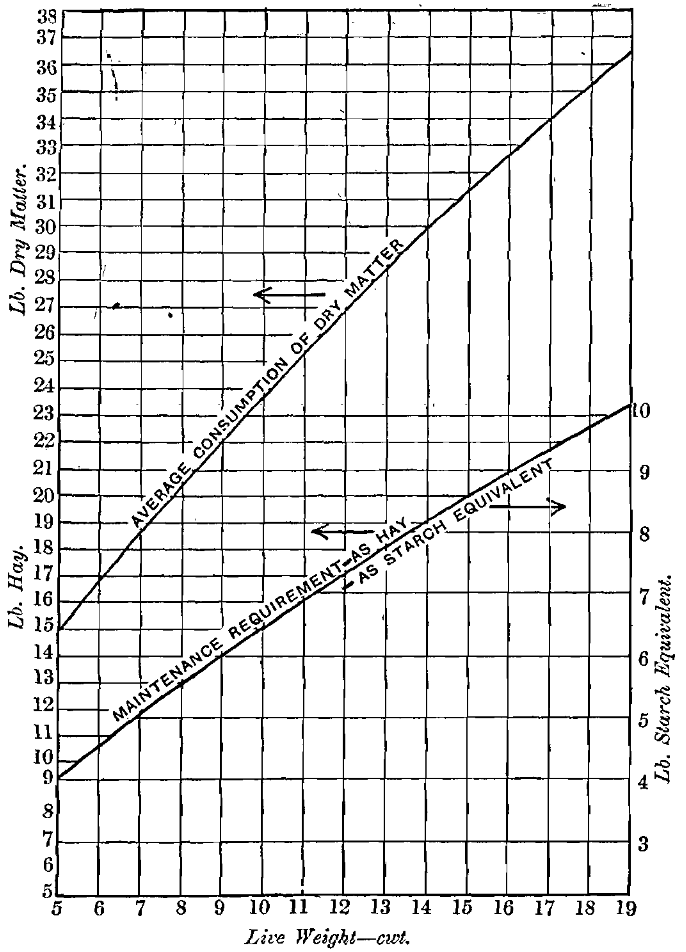

DIAGRAM III.

Estimate the number of Calories in this increase from Armsby's figures according to the age and condition of your animals.

Calculate the weight of starch equivalent required to produce such a number of Calories.

Calculate the weight of home grown fodder, usually roots, required to provide this weight of starch equivalent.

Check the weight of digestible protein in the ration of coarse fodder and roots.

Estimate how much concentrated food, such as cake or meal, is required to make up any deficiency.

Reduce the root ration according to the amount of starch equivalent contained in the cake or meal.

Write down the ration and check it once more, and if necessary make final adjustments.

The necessary information as to the composition of the various feeding stuffs can be found in Table II. and Diagram III., pp. 174 and 175.

This method of rationing leaves much scope for individual judgment and skill, for instance in judging the weight and condition of the animals, in deciding on the most convenient method of handling the feeding stuffs, in selecting the particular cakes and meals to be used to supplement the coarse fodder and roots and in many other details. The rations worked out in this way will be found to differ materially in one respect from those in general use among graziers, namely in that they contain far less cake and meal. The general tendency to use excessive amounts of these expensive feeding stuffs is a legacy from the days of the old Wolff standard rations, which were later admitted by Wolff himself to contain excessive amounts of protein. Wolff's rations in turn were a legacy of the old view that fat could only be formed from fat or protein. This was completely negatived more than 50 years ago by Lawes and Gilbert at Rothamsted, who showed that the chief source of fat in the animal body was carbohydrate.

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CHAPTER XXIV.

FATTENING CATTLE ON GRASS. FEEDING STORES. FEEDING SHEEP.

Fattening on Good Pasture.

In the last chapter winter fattening was discussed, and a method was suggested for computing rations. Many animals are, however, fattened in the summer on grass, in which case they ration themselves. Nevertheless, the nutrition of animals on grass cannot be passed over without comment. The total weight of dry matter which a steer will eat is in practice limited by the capacity of his paunch, and is fairly well known from winter feeding trials. It can be found by inspection of the average consumption curve in Diagram III., p. 175. The type of animal usually chosen for fattening on grass is the three-year-old steer weighing about 10 cwt. Such an animal on winter rations will eat 24 lb. per day of dry matter. Presumably it will eat the same amount when on grass in the summer.

The composition of the dry matter of grass, for instance, of the best quality of meadow hay is per 100 lb. 45 lb. of starch equivalent and 10 lb. of digestible protein. Exact figures are available for the composition of grass as grazed by animals, at any rate on well managed grazings where the grass is never allowed to grow long, and the animals consequently feed all the time on young new growth. The younger the grass the higher its digestibility, and the higher consequently the starch equivalent. Recent work has shown that the dry matter of closely grazed pasture contains 70 per cent

of starch equivalent including 20 per cent. of digestible protein.

A characteristic, and perhaps the most important one, of high class pasture is the denseness of the herbage. So many blades are produced per square inch that an animal on such a pasture can fill himself with a minimum of walking about in search of food. He need not, therefore, lead a more active life than that of a steer fattening in an open yard in the winter.

Assuming that the animal under discussion weighs 10 cwt. his needs for maintenance will be 6·5 lb. of starch equivalent (Diagram III., p. 175). He will eat 24 lb. of dry matter, which will contain 4·8 lb. of digestible protein and 16·8 lb. of starch equivalent. Subtracting the 6·5 lb. of starch equivalent required for maintenance, 10·3 lb. will be left for production. This corresponds to 10·3 × 1,071 or 1,100 Calories of net energy, enough to produce 1,100 ÷ 3,250 = 3·4 lb. of live weight increase.

Increases of over 3 lb. per head per day are rare because some of the starch equivalent is wasted in walking about. In the case of first class pastures, therefore, there is no need to supplement the pasture with cake or corn.

Fattening on Poor Pasture.

In poorer pastures this is not the case. The herbage being less dense, the animals are compelled to cover much more ground in order to fill themselves, and a considerable proportion of the net energy of the grass they eat is therefore transformed into the muscular work of walking, which reduces the proportion left for transformation into increased weight.

Poor pastures, too, are often under stocked: much of the grass grows old and its nutritive value greatly decreases, so that the starch equivalent may fall to 40 per cent. This will certainly be the case if the grazing is badly managed and the grass allowed to grow long and fibrous before the animals eat it.

To provide the 6·5 lb. starch equivalent required for maintenance, 100 × 6·5 ÷ 40, or 16 lb. of dry matter will be required. This will leave only 8 lb. of dry matter for production. Assuming that the muscular effort of walking in search of food uses up 2 lb., only 6 lb. will remain for production of increased weight. This will produce a daily increase of only 6 × 40 ÷ 100 × 1,071 ÷ 3,250 = ·8 lb. For store animals such an increase is often allowable though not satisfactory. For fattening animals it would be quite useless.

To produce satisfactory fattening on such a pasture, it would be necessary to supplement the pasture with some kind of cake or meal. Assuming the dry matter of such a pasture to contain 5 per cent. of digestible protein, the 24 lb. eaten per day would supply 1·2 lb. The protein deficiency is therefore quite small, and the supplement needed for fattening is chiefly starch equivalent. The provision of a supplement will reduce the need for walking, and consequently the extra consumption of net energy for muscular exercise will practically disappear.

To produce 2 lb. of live weight increase per day containing an average of 3,250 Calories per lb. will require 6 lb. of starch equivalent. For a 10 cwt. animal the maintenance ration requires 6·5 lb. The total requirements will therefore be 12·5 lb. of starch equivalent. Since the protein deficiency is small, it is not necessary to use a supplement very rich in that constituent. Palm nut kernel cake containing 17 per cent. of digestible protein and 75 per cent. of starch equivalent would be suitable, and is usually cheap. It might be mixed with an equal weight of maize containing 7 per cent. of digestible protein and 81 per cent. of starch equivalent. The mixture would then contain 12 per cent. of digestible protein and 78 per cent. of starch equivalent.

The problem now is to calculate how much of the dry matter of the pasture containing 40 per cent. of starch equivalent it will be necessary to replace by the palm kernel

cake—maize mixture to give a ration containing 12·5 of starch equivalent in the 24 lb. which the animal will eat.

8 lb. of the mixture	supply 8 × ·78 =	6·24 lb.	starch equivalent.
16 lb. of grass dry matter	,, 16 × ·40 =	6·4 lb.	,, ,,
24 lb.		12·64 lb.	,, ,,

The ration would then contain:—

8 lb. mixture	containing 12 per cent. dig. protein =	·96 lb.
16 lb. grass dry matter	,, 5 ,, ,, ,, =	·80 lb.
		1·76 lb.

Stores on Pasture.

This ration would produce satisfactory increase at the rate of something like 2 lb. per day, but the cost of 8 lb. per day of cake and corn would probably be excessive. The lesson is that fattening cattle on poor pasture is very expensive. This is the reason why poor pasture is generally used for raising young store animals which it will maintain at the slow rate of growth of about ¾ lb. per head per day. This is the method usually employed in raising many of the store cattle produced in the United Kingdom. The rest are wintered in yards on a ration of roots, hay, and straw which works out thus:—

Stores in the Winter.

Ration—

	Dry Matter lb.	Starch Equiv. lb.	Dig. Protein lb.
7 lb. poor hay containing	6	1·7	·24
7 lb. oat straw ,,	6	1·6	·07
20 lb. swedes ,,	2¼	1·5	·14
	14¼	4·8	·45

The protein requirement of such young stores weighing 5 cwt. is about 1 lb. per day of digestible protein if they are to make normal growth. Their maintenance requirement is 3·5 lb. of starch equivalent per day. Such a ration leaves

therefore only 4·8 — 3·5 = 1·3 lb. of starch equivalent for production of increased weight. This would supply only 1·3 × 1,071 Calories = 1,400 Calories of nett energy, which would provide for 1,400 ÷ 2,500 or ·56 lb. increase per day. The ration could be improved either by giving better quality hay, or more hay and less straw, or by supplementing it with say 2 lb. per day of linseed or other cake.

In the latter case the ration would work out thus :—

		Dry matter lb.	Starch Equiv. lb.	Dig. Protein lb.
7 lb. poor hay	containing	6	1·7	·24
6 lb. oat straw	,,	5	1·6	·07
20 lb. swedes	,,	2¼	1·5	·14
2 lb. linseed cake	,,	1¾	1·5	·50
		15	6·3	·95

Such a ration would supply 6·3 — 3·5 = 2·8 lb. of starch equivalent for production of increased weight, which would produce a daily increase of just over 1 lb. The ration could still be improved by using better quality hay.

Fattening Sheep.

The general principles of the winter feeding of sheep are practically the same as those already discussed in the case of cattle. There are, however, differences in detail which demand some difference in the method of working out rations. For instance, the common practice in winter mutton production is to fold the sheep on swedes or some similar crop which they consume practically *ad libitum*. Under these conditions a sheep of about 100 lb. to 120 lb. live weight will consume 140 lb. of roots per week. When the root crop is poor, root consumption is limited by moving the fold at longer intervals in which case the other constituents of the ration must be increased correspondingly.

A normal ration for sheep weighing 100 lb., stated per week to avoid fractions is :—

		Dry matter lb.	Starch Equiv. lb.	Dig. Protein lb.
5 lb. hay	containing	$4\frac{1}{4}$	1·8	·25
5 lb. cake mixture	„	$4\frac{1}{4}$	3·7	1·25
140 lb. swedes	„	16	10·2	1·0
		$24\frac{1}{2}$	15·7	2·50

The maintenance requirement of a 100 lb. sheep per week is 8·8 lb. of starch equivalent and not more than ·5 lb. of digestible protein. The above ration contains more protein than is necessary even for a fattening ration. It supplies too 15·7 – 8·8 or 6·9 lb. of starch equivalent for production, which is capable of producing in average animals an increase of $2\frac{1}{2}$ lb. per week, or just over 5 oz. per day. The $24\frac{1}{2}$ lb. of dry matter per week or $3\frac{1}{2}$ lb. per day is just about as much as a 100 lb. sheep will eat. The ration is a good ration except that it supplies too much protein. As in the case of fattening cattle, there is an almost universal tendency among farmers to overdo the protein in the ration of fattening animals, especially sheep. It may well be that this excessive consumption of protein is the cause of many of the sudden deaths among sheep folded on roots in the winter. The waste products of protein consumption are excreted by the kidneys. The extra work thrown on the kidneys by excessive protein consumption may cause a serious derangement which results in sudden death. In the absence, however, of accurate knowledge on the subject it is unwise to dogmatise. The following suggestions are directed to the question of reducing the nitrogen in the ration:—

Danger of too much Protein.

Without the cake mixture, the ration supplies 12 lb. of starch equivalent and 1·25 lb. of digestible protein. The cake mixture was calculated to contain 3·7 lb. of starch equivalent and 1·25 lb. of digestible protein. The ration supplied about the correct quantity of starch equivalent but ·85 lb. more protein than the sheep required. What is re-

quired, therefore, is a cake mixture capable of supplying 3·7 lb. of starch equivalent and only 1·25 — ·85, or ·4 lb. of digestible protein, a ratio of 9 parts of starch equivalent to 1 part of digestible protein. The cereals approximate most nearly to this ratio. In barley the ratio of starch equivalent to digestible protein is 11 to 1, in maize 10 to 1, in oats 7½ to 1, and in wheat 7 to 1. Barley or maize would be suitable for most of the mixture, and linseed cake or decorticated cotton cake might be the other constituents.

A mixture of 10 parts of barley or maize with 1 part of linseed cake or decorticated cotton cake would have approximately the correct composition. Of the linseed cake mixture, 5 lb. per week, of the cotton cake mixture 4 lb. per week would provide the necessary ·4 lb. of digestible protein, and about 3½ lb. of starch equivalent. The ration would then be:—

Per head per week for 100 *lb. sheep.*

140 lb. roots.
5 lb. hay.
5 lb. mixture of linseed cake 1 part, barley or maize 10 parts.
or 4 lb. mixture of decorticated cotton cake 1 part, barley or maize 10 parts.

Such a ration is quite in accord with the most recent measurements of the protein requirements of the sheep, and it is believed that sheep would make very satisfactory increases on it, and that they would keep healthy. It is at present, however, without the sanction of extended successful practice in this country, and might well be made the subject of feeding trials.

Having access to unlimited roots, the sheep will adjust their ration according to their size, and there is, therefore, not the same need to vary the ration according to the live weights of the animals, as was the case with cattle confined in yards or boxes when every constituent of the ration was

limited. Nor is there any reason to increase the protein supply as the sheep increase in weight, for it appears that the protein needs of the sheep do not increase after they reach 100 lb. live weight.

Effect of Cold.

One more point needs discussion, the effect of the low external temperature and of the consumption of the cold swedes on the maintenance requirements of the sheep. There are no measurements of the effect of a fall of temperature on the maintenance ration of sheep, but as the sheep is so much better clothed with wool than the pig, it is unlikely that the sheep would be more affected than the pig. The Cambridge measurements showed that the maintenance requirements of the pig increased at the rate of 5 per cent. of the requirement at 20° C. for a fall of 1° C. The normal requirement of the sheep is 8·8 lb. starch equivalent per week, which corresponds to 8·8 × 1,071 or 9,420 Calories.

The normal ration provides 15·7 lb. starch equivalent in the form of 140 lb. roots, 5 lb. hay, and 5 lb. cake and corn. The metabolisable energy of this ration is 20 lb. reckoned as starch. Therefore, in the processes of digestion and absorption 20 − 15·7 = 4·3 lb. of starch would be converted into heat, which could not be used for physiological purposes. Since 1 lb. of starch produces in the animal 1,707 Calories, this 4·3 lb. of starch would produce 7,340 Calories, which could be used to keep up the body temperature. But the 140 lb of roots would contain 124 lb. of water or 56 kilograms. Assuming that this is eaten at an average temperature of 4° C., it will be warmed through 36° C. to the body temperature of 40° C. This will require 56 × 36 = 2,016 Calories. Subtracting this from the above 7,340 calories, 7,340 − 2,016 or 5,324 Calories will be left to assist to maintain the body temperature. This is 5,324 × 100 ÷ 9,420 = 56 per cent. of the normal maintenance ration, and at 5 per cent. per degree it will neutralise a fall of temperature of 11° C. If the normal maintenance ration was measured at 18° C., there

will, therefore, be no need to increase it unless the temperature falls below $18 - 11 = 7°$ C. The rate of increase produced by a normal ration should, therefore, not fall off unless the temperature falls below 7° C. or 45° F., which of course it does in really cold weather.

Summarising the above discussion, it appears that if fattening sheep of about 100 lb. live weight are to make satisfactory progress, they should be allowed access to a ration containing per week 15½ lb. of starch equivalent and 1¾ lb. of digestible protein, which should not bulk to more than 24½ lb. of dry matter—the limit of the capacity of the digestive organs of sheep of this class. Of this ration the hay and cake and corn are usually fixed in amount, and the sheep are allowed to adjust their consumption to their requirements by giving them access to unlimited roots.

Towards the end of the period of fattening, the increase in live weight contains more fat and consequently more Calories per lb. To maintain the rate of increase, more Calories must be consumed. The capacity of the digestive organs limits the consumption of bulky materials such as roots and hay. The sheep should, therefore, be given more concentrated food, cereal grains or meal being the most suitable.

CHAPTER XXV.

RATIONS FOR MILCH COWS.

In the preceding chapters an attempt has been made to adjust rations for various kinds of animals so that within limits they may produce the desired result. This method of rationing has not been used in the practice of feeding for beef or mutton. It has, however, been for some time the accepted practice among the more advanced milk producers, and is widely sanctioned by good practical results. As generally practised, the method consists in first computing a maintenance ration according to the weight of the cow, and then supplementing the maintenance ration in proportion to her yield of milk, and, as a further refinement, according to its composition.

Maintenance Ration.

The maintenance ration of a cow will be the same as the maintenance ration of a steer of the same weight, and can be found by inspection of Diagram IV., p. 197. For a 10 cwt. cow it will be about 6,500 Cal. of net energy, or $6\frac{1}{2}$ lb. of starch equivalent, including about ·7 lb. of digestible protein.

Ration per Gallon of Milk.

Many investigations have been carried out with the object of ascertaining the amount of food required to produce 1 gallon of milk. The essential conclusions of these investigations are given below.

A gallon of average milk, containing 3·7 per cent. of butter

fat, if dried and burned in a bomb calorimeter, would give out about 3,000 Calories. If 1 lb. of starch equivalent produces 1,071 Cals. in the form of milk, as it is known to do in the form of live weight increase, then 1 gallon of milk would require 3,000 ÷ 1,071, or 2·8 lb. of starch equivalent for its production. This is, however, not the case, for 1 lb. of starch equivalent has been found to produce more Calories in the form of milk than it can produce in the form of live weight increase, and this in spite of the fact that a heavy milking cow on a correspondingly heavy ration does not digest her food so completely as a steer.

The reason for the increased yield of Calories in milk per lb. of starch equivalent is not clear. Whatever the reason, the fact remains, and has been measured, with the result that it has been found that 1 lb. of starch equivalent can produce 1,350 Cal. in the form of milk. On this basis 1 gallon of milk requires for its production only 3,000 ÷ 1,350, or 2¼ lb. of starch equivalent. But milk contains a high percentage of protein, on the average about ·4 lb. per gallon. There is however, a considerable loss in the conversion of the protein of the food into the protein of milk, and nitrogen balance experiments on milch cows have shown that on the average ·55 lb. of digestible protein is required per gallon of milk secreted in order to prevent the cow from losing nitrogen, which, of course, means losing flesh. A committee appointed by the Ministry of Agriculture has adopted 2½ lb. of starch equivalent, including ·6 lb. of digestible protein, as the standard requirement for producing 1 gallon of milk.

Standard Ration for Two-gallon Cow.

With these data, namely, that the food requirement per gallon of milk is 2½ lb. of starch equivalent, including ·6 lb. of digestible protein, it is possible to proceed at once to the computation of rations for milch cows.

It will be convenient to take as a basis the ration for a cow yielding 2 gallons of milk per day, as it is hardly worth while to weigh out an individual ration for a cow yielding

less than this. Such a cow, weighing 10 cwt. live weight, will require—

For maintenance ...	*6½ lb. starch equiv., and*	*·7 lb. dig. prot.*
For production of 2 gals.	5 lb. " "	" 1·2 lb. " "
Total ...	11½	1·9

This must be included in a ration containing about 27 lb. of dry matter which is the limit of such a cow's capacity for consumption.

A typical ration for a 10 cwt. cow, yielding 2 gallons of milk per day, would be:—

	Dry Matter. lb.	Starch Equiv. lb.	Diges. Protein. lb.
20 lb. average hay containing	17	7·0	1·0
40 lb. mangolds containing ...	4·3	2·2	·2
3 lb. bran *containing* ...	2·6	1·35	·32
2 lb. palm kernel cake ...	2·8	1·5	·34
Total	26·7	12·05	1·86

Varying the Ration.

This ration might be modified in a great variety of ways according to the feeding stuffs available. For instance, the 2 lb. of palm kernel cake might be replaced by 3 lb. of crushed oats. The bran might be replaced by an equal weight of cotton cake, or both the bran and the palm kernel cake by an equal weight of a half and half mixture of cotton cake and coconut cake. Some of the hay might be replaced by straw, in which case the deficiency of protein in the straw should be made good by replacing the bran by a feeding stuff rich in protein, as, for instance, decorticated cotton cake or ground nut cake. The roots might be increased at the expense of the hay, in which case also the concentrates should be richer in protein than are bran and palm kernel cake. Whatever replacements are made, the ration should be adjusted to contain

about 27 lb. of dry matter, about 11½ lb. of starch equivalent, and just under 2 lb. of digestible protein.

Feeding Dry Cows.

On such a ration a cow yielding 2 gallons of milk per day will maintain her weight. If the ration is continued as she dries off and until she calves again, she will store fat and protein in her own body and that of her calf.

The amounts of protein and fat stored in the calf are comparatively small. A newly-born calf of the average weight of 90 lb. contains 18 lb. of protein and about 40,000 Calories, which corresponds to a rate of growth during the period of gestation of about 1 oz. of protein and 140 Calories per day.

Ration per Gallon above Two Gallons.

For cows yielding over 2 gallons of milk per day, it is necessary to add to the above ration 2½ lb. of starch equivalent, including ·6 lb. of digestible protein for each extra gallon, Since the standard 2-gallon ration given above contains about 27 lb. of dry matter, which is about the limit of a 10-cwt. cow's capacity for bulk, it is necessary to give the extra productive ration in a very concentrated form, or the cow will not be able to find room in her digestive organs for the whole ration, and will reject part of the constituent which she finds least palatable, probably the hay or straw.

Milk Mixtures.

The most concentrated feeding stuffs are the oil-seed residues, the cereals, and certain industrial by-products, such as gluten feed and gluten meal. Of these the only one which is of exactly the right composition to be used alone is gluten feed, which contains 20 per cent. of digestible protein, and 75 per cent. of starch equivalent. Consequently 3⅓ lb. of this feeding stuff will supply exactly 2½ lb. of starch equivalent and ·6 lb. of digestible protein, and will, therefore, suffice for the production of 1 gallon of milk.

It is impossible, however, to adopt this as a general standard productive ration per gallon, firstly, because the quantity of it on the market is limited, and, secondly,

because it is made from maize, and maize proteins are not very good. In general it will be necessary to use a mixture of oil-seed products and cereals so adjusted that it may contain 20 per cent. of digestible protein, and 75 per cent. of starch equivalent.

Such mixtures are:—

I. 3 parts maize,
 2 parts ground nut cake (decorticate
II. 1 part maize,
 2 parts oats,
 2 parts decorticated cotton cake.
III. 6 parts palm kernel cake,
 1 part ground nut cake (decorticated).
IV. 4 parts palm kernel cake,
 1 part decorticated cotton cake.

Each of these mixtures contains approximately 20 per cent. of digestible protein and 75 per cent. of starch equivalent, and should, therefore, be used at the rate of $3\frac{1}{3}$ lb. per gallon of milk secreted above 2 gallons per day, of course as a supplement to the standard ration.

Cows of Varying Weight.

For cows of varying weight, it is necessary to alter the basal ration according to the weight. Usually the concentrated part of the ration and the roots are kept constant, and the coarse fodder altered in accordance with the maintenance curve, Diagram IV., p. 197. Thus a ration for a large cow weighing 12 cwt., and yielding per day 4 gallons of milk would be—

	Dry Matter. lb.	Starch Equiv. lb.	Diges. Protein. lb.
22 lb. hay	19	7·7	1·2
40 lb. mangolds	4·3	2·2	·2
3 lb. bran	2·6	1·35	·32
3 lb. palm kernel cake ...	2·8	1·5	·34
	28·7	12·75	2·06

For extra 2 gals., $6\frac{2}{3}$ lb. cake mixture...	6·0	5·0	1·3
Total ration	34·7	16·75	3·36

Heavy milking cows usually have good appetites, but in many cases it would happen that 34·7 lb. of dry matter would be more than they would eat. For this reason the ration might be modified by replacing some of the hay by an extra allowance of roots in proportion to their starch equivalent. Thus, to replace 8 lb. of hay by roots: the starch equivalent of hay per 100 lb. is 35. Therefore 8 lb. of hay contain 2·8 lb. of starch equivalent. The starch equivalent of mangolds per 100 lb. is 5·5. Therefore 2·8 lb. of starch equivalent is contained in 50 lb. of mangolds, which is the weight of mangolds which should replace 8 lb. of hay.

The ration would then be:—

	Dry Matter lb.	Starch Equiv. lb.	Diges. Protein. lb.
14 lb. hay	12	4·9	·8
90 lb. mangolds	9·6	5·0	·4
3 lb. bran	2·6	1·35	·32
3 lb. palm kernel cake ...	2·8	1·5	·34
	27·0	12·75	1·86
For extra 2 gallons, $6\frac{2}{3}$ lb. cake mixture	6·0	5·0	1·3
	33·0	17·75	3·16

The replacement of part of the hay by roots has decreased the dry matter of the ration by nearly 2 lb., which will bring the total ration within the appetite of so large a cow. A further decrease could be made by replacing the bran by 2 lb. of a more concentrated feeding stuff, such, for instance, as one of the cake mixtures, or by further decreasing the hay

by replacing it with cake mixture. The problem in feeding heavy milking cows is to get sufficient protein and starch equivalent in a ration which is within their appetite. The solution in general is to limit the coarse fodder, giving the milk ration first, plus a little hay.

Varying Composition of Milk.

In computing the rations given above, the standard ration adopted—$2\frac{1}{2}$ lb. starch equivalent and ·6 lb. digestible protein per gallon—is based on the food requirements per gallon of average milk containing 3·7 per cent. of butter fat. If the milk varies in composition, the ration per gallon will also vary as shown below :—

Butter Fat in Milk, per cent.	Ration per Gallon. Starch Equiv. lb.	Dig. Protein. lb.	Cake Mixture. lb.
2·0	1·7	·55	2·3
3·0	2·1	·57	2·8
3·75	**2·5**	**·6**	**3·3**
4·0	2·6	·66	3·5
5·0	3·1	·7	4·2

Milk Recording and Individual Feeding.

The method of rationing milch cows described above implies individual rationing, and this implies a definite knowledge of the live weight and milk yield of each cow. It must, therefore, go hand in hand with milk recording, It also involves additional labour and constant supervision. The labour can be much reduced by giving a general basel ration adjusted as above according to the average live weight of the herd. A measure is then made to hold the weight of cake mixture required for one extra gallon. The yield of each cow is chalked up over her manger, and she is given one or more measures of cake mixture according to her milk yield. This is usually quite good enough for practical

purposes, and will lead to considerable economy in the cost of food.

The alternative method of giving all cows the same ration, often without relation even to the average milk yield of the herd, will cause the poor milkers to get unduly fat, and the good milkers to lose flesh, with great detriment to the milk yield in each case, and a correspondingly increased cost of food per gallon of milk.

Effect of Feeding on Milk Yield.

Finally, it must not be forgotten that the capacity for yielding milk is an inherent character of each individual cow, and cannot be appreciably increased by feeding, though it can be decreased by deficient feeding. To overfeed a poor milker simply results in her getting unduly fat, and is most uneconomical. Within the limits of good practice the average composition of the milk of an individual cow is also an inherent character, and is capable of but slight alteration by feeding unless the ration is so unsuitable as to derange her normal health, as, for instance, by causing scouring.

Need for Skill in Management.

The system of rationing described above does not by any means replace the individual skill of the milk producer. He still requires to exercise great judgment in purchasing or breeding animals of good inherent milking capacity, in watching the condition of his cows, and the completeness with which they take their ration, adjusting it if necessary as his judgment indicates. He should endeavour to acquire a wide knowledge of many of the properties of feeding stuffs which cannot be described in print or measured in terms of Calories or starch equivalents. Thus, for instance, all cruciferous crops—swedes, turnips, cabbages, kale, etc.—tend to give to milk, and especially to butter, an acrid flavour, which can be mitigated by feeding them after rather than before milking. Cotton cake tends to prevent the scouring which sometimes results from the consumption of a heavy root ration. Linseed cake produces soft butter, cotton cake

hard butter. Barley is said to have a very bad effect on the yield of milk. Many such points as these will be acquired by constant observation.

Cows on Good Pasture.

Cows, as a rule, spend the summer at grass, and it is, therefore, desirable to discuss their nutrition at this period. Referring back to Chapter XXIV., p. 178, where the nutrition of fattening steers on grass was discussed, it was stated that on good pasture well managed the dry matter of the herbage as eaten would contain 70 per cent. of starch equivalent and 20 per cent. of digestible protein. A deep milking cow, weighing, say, 12 cwt., would eat per day an amount of such herbage which would contain 30 lb. of dry matter. This amount of dry matter would supply her with 21 lb. of starch equivalent and 6 lb. of digestible protein, which is approximately the ration for a 12 cwt. cow giving $5\frac{1}{2}$ gallons of milk per day. The great palatability of such herbage would probably induce her to eat even more than 30 lb. of dry matter, in which case it would certainly provide an abundant ration. Even heavy milkers, therefore, require no extra food when they are on good well managed pasture.

Cows on Poor Pasture.

If, however, the pasture is poor by nature, and is badly managed, and allowed to grow long and benty, or if for any other reason its quality falls off, as is often the case towards August and September, the case is very different. Under these circumstances the dry matter of the pasture may well contain only 30 per cent. of starch equivalent and 5 per cent. of digestible protein. The 30 lb. of dry matter consumed by a cow per day would in this case yield only 9 lb. of starch equivalent and 1·5 lb. of digestible protein. Subtracting the maintenance ration of a 12 cwt. cow, which is approximately 7 lb. of starch equivalent and ·8 lb. of digestible protein, the remaining 2 lb. of starch equivalent and ·7 lb. of digestible protein is barely sufficient for the production of 1 gallon of milk.

Pastures, however, seldom become as poor as this. A more usual condition would be that the dry matter of the pasture as eaten would contain 40 per cent. of starch equivalent and 7 per cent. of digestible protein, which corresponds to a daily consumption per cow of about 12 lb. of starch equivalent and 2·1 lb. of digestible protein. After subtracting maintenance requirements there would remain 5 lb. of starch equivalent and 1·3 lb. of digestible protein, which would suffice for the production of 2 gallons of milk. This is a frequent occurrence in the late summer and autumn, when it often happens that a supplement is necessary for cows yielding more than 2 gallons per day. At this time of the year the cows should be watched carefully. If the heavier milkers show signs of losing flesh they should be given a cake mixture such as mentioned on p. 190, at the rate of $3\frac{1}{3}$ lb. per gallon for each gallon they yield above 2 gallons per day.

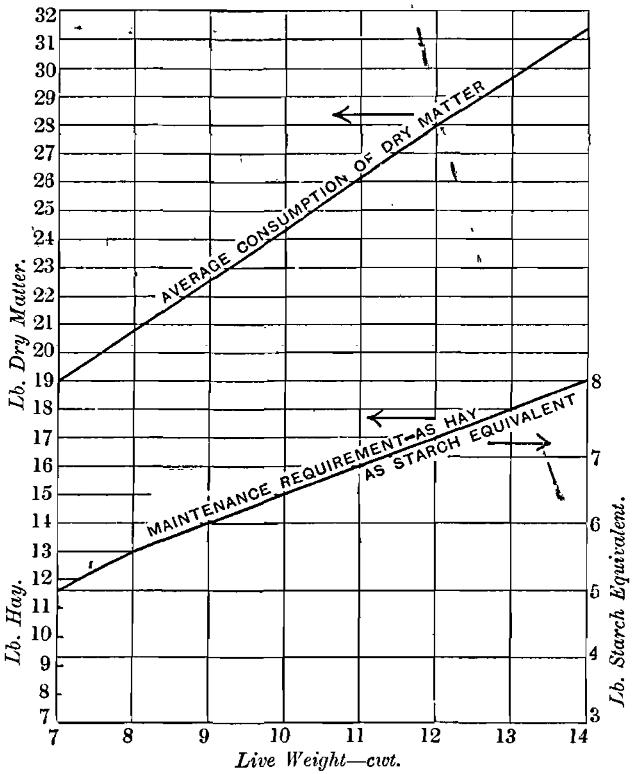
If this is not done, loss of flesh is soon followed by decreased milk yield, and when once the yield has fallen it is difficult to restore it.

It must not be forgotten that the maintenance ration does not allow for the consumption of energy in walking. Nor does the bare allowance of $2\frac{1}{4}$ lb. starch equivalent per gallon of milk. The extra $\frac{1}{4}$ lb. in the accepted standard allowance may be taken as a contribution towards the energy used in movement.

TABLE III.—FEEDING STUFFS FOR MILCH COWS.

	Dry Matter per cent.	Digestible Protein Equivalent per cent.	Starch Equivalent per 100 lb.	Nutritive Ratio 1 :	Manurial Value per ton—Shillings	Remarks.
Kohl Rabi	12 7	·5	8·3	11	—	
Mangolds — White-fleshed Globe ...	10·7	·4	5·5	11	—	
Potatoes	23·8	·6	17·8	16	—	
Swedes	11·5	·7	7·3	7	—	
Cabbage — Drum-head	11·0	·9	6·6	6	—	
Kale	14 8	1·4	8·8	5	—	
Silage — Oat and Tare	30 0	2·8	11·6	5	—	
Hay—Very good ...	84·0	9·2	48	5	—	
,, —Poor	85·7	3·4	24	11	—	
Straw—Oat ...	86·0	1·0	23	39	—	
,, —Barley ...	86·0	·8	24	52	—	
Maize	87	7·1	81·4	11	13	
Oats	86·7	8·0	59·5	7	13	
Beans	85·7	20·1	65 8	2·5	32	
Coconut Cake ...	88·6	16·2	79·1	4	30	
Cotton Cake, Egyptian	87 9	17·6	41·8	2	34	
Cotton Cake, Decorticated	90·2	34·6	70·7	1·2	54	
Ground Nut Cake, Decorticated ...	89·7	42 0	73·0	·8	55	
Ground Nut Cake, Undecorticated ...	89·7	27·7	56·8	1·4	35	
Linseed Cake ...	88·8	25·3	74·0	2	38	
Maize Germ Meal ...	89·3	10·4	85·3	7	20	
Palm Kernel Cake...	89 0	17·1	74·9	4	23	
Maize Gluten Feed	89·6	20·0	75·6	3	27	
Maize Gluten Meal	90·9	30·6	81·5	2	43	
Wheat — Middlings	87·0	13·5	70·0	4·5	22	
Wheat Bran ...	86·4	10·6	45·0	5	26	
Pasture— Very good ... / Average ... / Poor	25	5	17	4	—	Variation in crop per sq. yd.

RATIONS FOR COWS—PER DAY.



A cow requires for maintenance ·6 to ·8 lb. of digestible protein per day according to size. Production of 1 gallon of milk requires $2\frac{1}{2}$ lb. starch equivalent, including ·6 lb. of digestible protein.

DIAGRAM IV.

CHAPTER XXVI.

FEEDING HORSES FOR WORK PRODUCTION.

Early Views.

The earlier investigators of the physiology of work production adopted the assumption that since work was done by the contraction of the muscles, and since the muscles were composed essentially of protein and water, protein must be the source of muscular energy, and consequently of work. These early investigators experimented with carnivorous animals such as dogs, whose diet consists mainly of protein, and their method of investigation was to estimate the nitrogen excreted in the urine during periods of rest and work. Under these conditions they almost invariably found that the performance of work increased the excretion of urinary nitrogen. Since the nitrogen in the urine is a measure of the rate of decomposition of protein in the body, they naturally concluded that the increased decomposition of protein was the source of the energy required for the performance of the work.

Protein not Sole Source of Muscular Energy.

As these experiments were repeated from time to time, certain investigators, notably Fick and Wislicenus, obtained results which were at variance with this theory. These two experimenters, after abstaining from food containing protein for some time, climbed the Faulhorn, a mountain over 6,000 feet high, and estimated the nitrogen in their urine during the six hours occupied in climbing and the subsequent seven hours rest. They found no appreciably increased excretion of nitrogen during the climbing period,

and in addition to this the number of foot pounds of work done in lifting their bodies to the height of the mountain corresponded to about three times as many Calories as could have been produced by the oxidation of the whole of the protein decomposed during the period as measured by the excretion of nitrogen in their urine. This was generally accepted as proving that protein was not the only source of muscular energy.

Carbohydrate Chief Source of Muscular Energy.

It was Kellner's experiments with the horse which finally cleared up the question. Kellner estimated the nitrogen excreted per day by a horse doing variable amounts of work, and at the same time found the animal's live weight by weighing. He found that the performance of a small amount of work neither increased the excretion of nitrogen nor diminished the live weight. A large amount of work, however, decreased the live weight of the horse and increased the excretion of nitrogen. A large amount of work was, however, performed by the horse without loss of live weight or increase in nitrogen excretion if a certain quantity of starch was added to his ration.

Kellner interpreted these results to mean that work is done preferably at the expense of the non-protein constituents of the body. If the work is increased so much that these constituents do not supply energy enough for its performance, then the animal is compelled to decompose the protein of its muscles; its live weight consequently falls and its excretion of nitrogen increases. If more non-protein is provided by adding starch to the ration, this is used in preference to protein, there is no increased excretion of nitrogen and the live weight remains constant.

This explanation of Kellner's reconciled the divergent results of former investigators. On examination in the light of Kellner's work it appeared that those investigators who had found increased nitrogen excretion as a result of work had used rations deficient in non-nitrogenous constituents so

that their animals had been compelled to decompose protein to provide the necessary energy. On the other hand, whenever a sufficiency of non-nitrogenous constituents had been used no increase in nitrogenous excretion had resulted from the performance of work. From this time onwards it has been generally accepted that work is done at the expense of the non-nitrogenous constituents of the body—the carbohydrates and fats—which as they are exhausted are replaced by the carbohydrates and fats of the diet, and that protein is only decomposed for the production of energy for muscular work when carbohydrates and fats are not available.

Recent Work.

More recent investigators have studied the relation between the consumption of protein, fat, and carbohydrate, and the amount of muscular work performed, by the much more direct method of measuring the volume of carbon dioxide expired in the breath and the volume of oxygen used during periods of rest and work.

Respiratory Quotient.

Before this method can be fully understood it is necessary to examine shortly the oxidation of the various food constituents. A typical carbohydrate, for instance grape sugar, is oxidised according to the equation:—$C_6H_{12}O_6 + 6O_2 = 6H_2O + 6CO_2$. Six molecules of oxygen are used in the production of six molecules of carbon dioxide, and since equal volumes of all gases at the same temperature and pressure contain the same number of molecules, the volume of oxygen used is the same as the volume of carbon dioxide produced. The ratio of the volume of carbon dioxide produced to the volume of oxygen consumed is therefore 1. This ratio is known as the respiratory quotient. It is 1 in the case of all carbohydrates, since they all contain just enough oxygen to oxidise all their hydrogen, and on oxidation only consume enough oxygen to oxidise their carbon.

A typical fat, for instance tristearin, is oxidised thus:—$(C_{17}H_{35}CO_2)_3C_3H_5 + 81{\cdot}5O_2 = 55H_2O + 57CO_2$. The respira-

tory quotient will therefore be $\frac{57}{81 \cdot 5} = \cdot 7$. It is impossible to write an equation for the oxidation of protein because its formula is not known, but from its average percentage composition, after allowing for the incompletely oxidised compounds excreted in the urine, it is estimated that its average respiratory quotient is approximately ·8, though the exact figure will vary somewhat according to the nature of the nitrogenous excreta.

The following table takes into account the variations in respiratory quotient and provides figures from which the heat production can be calculated if the oxygen consumption is known.

Calories produced per litre of oxygen consumed—

Respiratory *Quotient.*	0	1	2	3	4	5	6	7	8	9
·7	4·689	4·690	4·702	4·714	4·727	4·739	4·752	4·764	4·776	4·789
·8	4·801	4·813	4·825	4·838	4·850	4·863	4·875	4·887	4·900	4·912
·9	4·924	4·936	4·948	4·960	4·973	4·985	4·997	5·010	5·022	5·034
1·0	5·047									

Modern Experimental Method.

The method of experimenting is as follows:—By a suitable arrangement, to be described later, the volume of oxygen consumed and the volume of carbon dioxide produced during a measured time are accurately measured. The volume of carbon dioxide divided by the volume of oxygen gives the respiratory quotient. The above table is then consulted to find the heat production per litre of oxygen, and this figure multiplied by the volume of oxygen consumed gives the heat production in the measured time.

Indirect Calorimetry.

This method of experimenting is known as indirect calorimetry, because it gives by an indirect method the rate of production of heat in the body. It has been compared with direct calorimetry, where the animal is confined in a calorimeter, as described in

Chapter XXI. The direct and indirect methods have bee found to give identical results. The indirect method possess many advantages for the measurement of the heat requir for muscular work, because it can be used for animals workin in natural conditions. It is obviously impossible for a horse, for instance, to work normally inside a calorimeter.

The method of experimenting by indirect calorimetry with the horse is first to perform the operation known as tracheotomy, by means of which a tube is permanently fixed in the trachea, or windpipe, as it is commonly called. To this tube is attached a rubber tube connected with an expanding air-tight bag, which can hold several hundred litres of expired air.

The bag is fixed on the horse's back, and at the beginning of each experiment is completely collapsed. The rubber connecting tube is provided with a three-way stop cock, which, when turned one way, connects the trachea with the open air, so that the animal does not breathe into the bag, but when turned through one right angle connects the trachea with the bag, which is then filled with the expired air. When the stop cock is turned through two right angles the bag is closed, and the animal again expires into the open air. There is also in the connecting tube a valve which admits the inspiration of fresh air, but directs the expired air into the bag.

Resting Metabolism.

The apparatus having been fixed in position, the animal is allowed to rest for some time. Whilst the animal is still at rest the stop cock is turned so that the expired air flows into the bag and kept in this position for a time accurately measured by a stop watch. The stop cock is then turned, and the bag detached, a small measured sample of expired air taken from it for analysis, and the rest forced out through a gas meter so as to ascertain its volume. In analysing the sample of air the carbon dioxide is absorbed by potassium hydrate solution, the decrease in volume giving the volume of carbon dioxide. The oxygen is then absorbed by alkaline solution of

potassium pyrogallate, the decrease in volume giving the volume of oxygen in the measured sample. The volumes of carbon dioxide and oxygen in the whole volume of air expired in the measured time are then calculated. The volumes of these gases in the inspired air are then calculated from the known composition of fresh air. Comparison of the volumes in the inspired and expired air then gives the volumes of oxygen consumed and carbon dioxide produced during the experiment. From these volumes the respiratory quotient is calculated. The table, p. 201, is then consulted to find the number of Calories produced per litre of oxygen at this respiratory quotient, and this figure multiplied by the volume in litres of oxygen consumed during the experiment gives the amount of heat produced by the resting animal in a measured time. Dividing by the time of the experiment in minutes the rate of heat production per minute of the resting animal is obtained. The bag is then again placed in position and the experiment repeated several times in order to obtain a reliable average result.

Working Metabolism.

When the experimenter is satisfied with the accuracy of this result, the apparatus is again adjusted and a set of experiments carried out while the horse walks. The horse is then harnessed to a cart or a plough, or made to perform any other kind of work. As soon as work is proceeding steadily, a set of experiments is carried out as before. The average results give the rate of heat production per minute by the horse when resting, walking, and working. These rates of heat production are known as the resting metabolism, walking metabolism, and working metabolism. By recording the time occupied in resting, walking, and working, and multiplying each period in minutes by its respective rate of metabolism, the sum of the results will give the total metabolism per day in Calories. This will be the number of Calories of net energy which must be supplied in the horse's daily ration. By dividing it by 1,071, the number of Calories of net energy in 1 lb. of

starch equivalent, the daily ration will be obtained in terms of lb. starch equivalent.

Thus, suppose that a series of experiments with an ordinary farm horse, weighing about 13 cwt., carried out as above show that the metabolism per minute is :—

At rest	3·47 Cal.
Walking	6·72 „
Ploughing	13·15 „

Again, suppose that the average division of the horse's time per 24 hours is :—

At rest	8 hours
Walking	8 „
Ploughing	8 „

Then his total net energy requirement per 24 hours will be :—

8 hours' resting at
3·47 Cal. per min. = 8 × 60 × 3·47 = 1665 Cal.
8 hours' walking at
6·72 Cal. per min. = 8 × 60 × 6·72 = 3225 „
8 hours' ploughing at
13·15 Cal. per min. = 8 × 60 × 13·15 = 6312 „

24 hours 11,202

This may be expressed in another way more comparable with the method employed in the earlier chapters :—

Maintenance requirements—
24 hours at
3·47 Cal. per minute = 24 × 60 × 3·47 = 4995 Cal.

Production requirements—
16 hours' walking at
(6·72 − 3·47) Cal. per min. = 16 × 60 × 3·25 = 3120 Cal.
8 hours' ploughing at
(13·15 − 6·72) Cal. per min. = 8 × 60 × 6·43 = 3087 Cal.

11,202

If it were always possible to measure the work done by a horse, this method would form the basis of an accurate and generally applicable system of rationing horses. In some cases this can be done. For instance, in ploughing an acre of land, if the average width of the furrow is 10 inches, the horse will walk 17,424 yards. The average pull exerted by a pair of horses in ploughing average land is about 330 lb., as measured by a dynamometer inserted between the horses and the plough. The work done by each horse in ploughing an acre is 17,424 × 165 or 2,874,960 foot-pounds.

Efficiency of the Horse.

Now the amount of heat which can be produced by the expenditure of 1 foot-pound of work has been accurately measured, and found to be ·000324 Cal. Consequently 2,874,960 foot-pounds corresponds to 2,874,960 × ·000324, or 932 Cal. The horse requires food supplying 3,087 Cal. to make good the material he oxidises in ploughing an acre. He, therefore, expends 3,087 Cal., and produces work corresponding to 932 Cal., or the useful work produced is 32 per cent. of the Calories expended in producing it. This percentage is called the net efficiency, because in determining it the Calories expended by the horse in maintenance and in walking are not taken into account. The total Calories consumed per day by the horse are 11,202. On this total consumption the horse performs useful work corresponding to 932 Calories. His overall efficiency is, therefore, 932 × 100 ÷ 11,202, or 8·3 per cent., or about that of a first-class modern steam engine.

Net and Gross Efficiency.

It should be noted that no machine is able to transform heat into work without very great loss. The percentage of the heat supplied to the machine which reappears as useful work is known as the efficiency of the machine. In the case of the horse, or other working animal, there are two ways of calculating the efficiency. The gross or overall efficiency is the useful work as a percentage of the gross Calorie consumption. The net efficiency is the useful work as a percentage of the extra

Calories over and above basal requirements consumed in producing the useful work.

Varying Efficiency.

The net efficiency of an animal in good working condition when performing its accustomed task is about 33 per cent. The net efficiency varies according to the condition of the animal, the severity of the work, and the training which the animal has received. In the case of an animal in poor condition doing severe work to which it is not accustomed, the net efficiency may be as low as 20 per cent. An animal in good condition doing its usual routine work, may attain a net efficiency of nearly 40 per cent. Rapid walking, trotting, or galloping is very severe work, and is, consequently, performed at a low efficiency, but this is much improved by training.

Computing Rations.

With this knowledge it would be possible to compute rations for horses on the basis of the amount of work done if it were possible to measure the work done in foot-pounds. Suppose, for instance, a similar horse to the one used for the experiment described above were required to produce five million foot-pounds of work per day instead of just under three million. Then five million foot-pounds correspond to 5,000,000 × ·000324, or 1,620 Cal. Assuming that the net efficiency of the horse is about the average, 33 per cent., the ration required to produce 1,620 Cal. would be 1,620 × 100 ÷ 33, or 4,860 Cal. of net energy.

Assuming also that the resting and walking metabolism are as before, the total ration would be :—

24 hours' resting metabolism at 3·47 Cal. per min.	4995 Cal.
16 hours' walking " " 3·25 " " "	3120 "
5,000 ft.-lb. at 33 per cent. efficiency	4860 "
	12,975 "

The total ration would, therefore, be 12,975 Cal. of net energy, or 12,975 ÷ 1,071 = 12 lb. of starch equivalent.

The difficulty in using this method is in the measurement of the work done. There is no practicable method of measuring or even estimating the work done in the endless variety of "jobs" required of a farm horse. Even in a straightforward task such as ploughing the work done per acre will vary according to the texture of the soil, the number of turnings, the width of the furrow, the degree of consolidation, the weather, the slope of the land, and the type of plough. The discussion of the method has, however, served to illustrate the general principles of work production, and to indicate the directions in which further information is required.

Effect of Low Temperature.

It will be noticed that the net energy required for maintenance is less in the horse than in cattle of equal weight. At low temperatures the maintenance ration of net energy will not ordinarily be associated with sufficient thermic energy to maintain the body temperature, and the maintenance ration must, therefore be increased or the animal will be compelled to oxidise its own tissues, and will, therefore, lose flesh. For practical purposes, however, this is of no importance, for under practical conditions a horse will always receive a working ration which will supply abundance of thermic energy for temperature maintenance.

For practical purposes all that can be done at present is to make rough estimates for the rations of ordinary farm horses working at varying degrees of severity.

The ration of hay and oats thus computed will probably be approximately correct, To correct it more nearly, watch the condition of the horse, and raise or lower the oat ration according as he loses or gains flesh.

Substitutes for Oats.

Good hay and oats are the standard constituents of the ration of horses in this country, but they can be partly replaced by other feeding stuffs quite satisfactorily if due precautions are observed. For instance, in eastern countries where oats cannot be

grown, the oat ration is commonly replaced by a mixture of barley and gram, even in the case of horses required to do fast work. The necessary precautions are that the replacement should be made in proportion to the content of net energy or starch equivalent. Thus, the starch equivalent of oats being 59·5 and of maize 81·4, the amount of maize which will replace 1 lb. of oats is $\frac{59{\cdot}5}{81{\cdot}4}$, or ·73 lb. For all practical purposes, therefore, 3 lb. of maize will take the place of 4 lb. of oats.

Again, in the case of bran with a starch equivalent of 45, 1 lb. of oats is equivalent to $\frac{59{\cdot}5}{45}$, or 1·32 lb. of bran, so that 4 lb. of bran are required to take the place of 3 lb. of oats. Other feeding stuffs which can be used in place of oats are barley, gram, palm kernel cake, beans, gluten feed, dried grains. In each case the proportion required to replace 1 lb. of oats should be calculated as above.

Rations computed in this way will always contain sufficient protein. They will certainly be more likely to contain too much than too little. In the case of horses required to do fast work, it may be necessary to decrease the bulk of the ration by replacing some of the hay given for maintenance by a quantity of oats calculated to supply an equivalent amount of starch equivalent.

How to Use Diagram V.

To compute rations from Diagram V and Table IV., first estimate as nearly as possible the live weight of the horse. Read off from the maintenance requirement curve on Diagram V. the maintenance ration for the estimated weight. This is given in terms of good hay on the left of the diagram, and in terms of starch equivalent on the right. If good hay is available, the amount to use is read off at once. If the quality is poor, more must be given. If hay is not available, and you are forced to use say oat straw, read the weight of starch equivalent required and give enough oat straw to contain that

amount. Thus a 13 cwt. horse requires 5 lb. of starch equivalent. The starch equivalent of oat straw per 100 lb. is 17. To get 5 lb. of starch equivalent, therefore, 100 ÷ 17 × 5 = 30 lb. of oat straw is required. This is more than the horse would eat. Half this amount, or 15 lb., would satisfy the horse's need for bulk, and would supply 2·5 lb. starch equivalent. The remaining 2·5 lb. required for maintenance would be made up by giving 100 ÷ 59·5 × 2·5 or 4 lb. of oats. An alternative would by 100 ÷ 45 × 2·5 or 5½ lb. of bran. The above three alternative maintenance rations would be—

(1) 12¼ lb. of good hay,
(2) 15 lb. oat straw and 4 lb. of oats,
(3) 15 lb. oat straw and 5½ lb. of bran.

Rations (2) and (3) would not be suitable for a horse which is required to do severe work. Their bulk would make it difficult for the horse to eat the necessary additional productive ration. Having decided on the maintenance ration, the next step is to estimate the degree of severity of the work on which the horse is to be employed. This can only be done very roughly as light work, medium work, or heavy work, for which a productive ration must be given in addition to the maintenance ration. Thus, for light work such as carting, a farm horse of average size requires in addition to its maintenance ration, about 5 lb. of starch equivalent, for medium work, such as ploughing, about 8 lb. of starch equivalent, and for heavy work such as pulling a binder, about 11 lb. of starch equivalent per day.

If the productive ration is to be oats, the following amounts are required:—

light work	100 ÷ 59·5 × 5	= 8½ lb. oats,
medium work	100 ÷ 59·5 × 8	= 13½ lb. oats,
heavy work	100 ÷ 59·5 × 11	= 18 lb. oats.

TABLE IV.

	Dry Matter, per cent.	Digestible Protein, Equivalent per cent.	Starch Equivalent, per 100 lb.	Weight to Replace 1 lb. Oats, lb.	Manurial Value—per Ton—Shillings
Kohl Rabi	12·7	·5	8·3	7·0	—
Mangolds—Red or yellow fleshed ...	13·2	·4	6·8	9·0	—
Carrots	13·0	·6	8·8	6·7	—
Pasture—Good / ,, Poor ...	25·0	5·0	17 0	$3\frac{1}{2}$	—
Clover and Rye—Grass-green ...	22·0	2·3	12·0	5·0	—
Hay—Good ...	84·0	9 2	48 0	1·5	—
,, Poor ...	85·7	3 4	24·0	3·2	—
,, "Seeds" ...	86 0	6·2	29·0	2·5	—
Oat Straw	86·0	1·0	23·0	3·5	—
Oats	86·7	8 0	59·5	1·0	13
Barley	85·1	6·5	71·0	·83	15
Maize	87·0	7·1	81·4	·73	13
Beans	85·7	20·1	65·8	·9	32
Gram	89·0	18·0	71·0	·83	30
Linseed Cake ...	88·8	25·3	74·0	·8	38
Palm Kernel Cake	89·0	17·1	74·9	·8	23
Brewers' Grains—Dried	89·7	13·0	48·3	1·23	24
Bran	86 4	10·6	45·0	1·32	26

Farm horse requires in addition to maintenance ration :—

If at light work ... ... 5 lb. st. equiv. per day.
,, medium work ... ... 8 lb. ,, ,,
,, heavy work ... ... 11 lb. ,, ,,

RATIONS FOR HORSES.

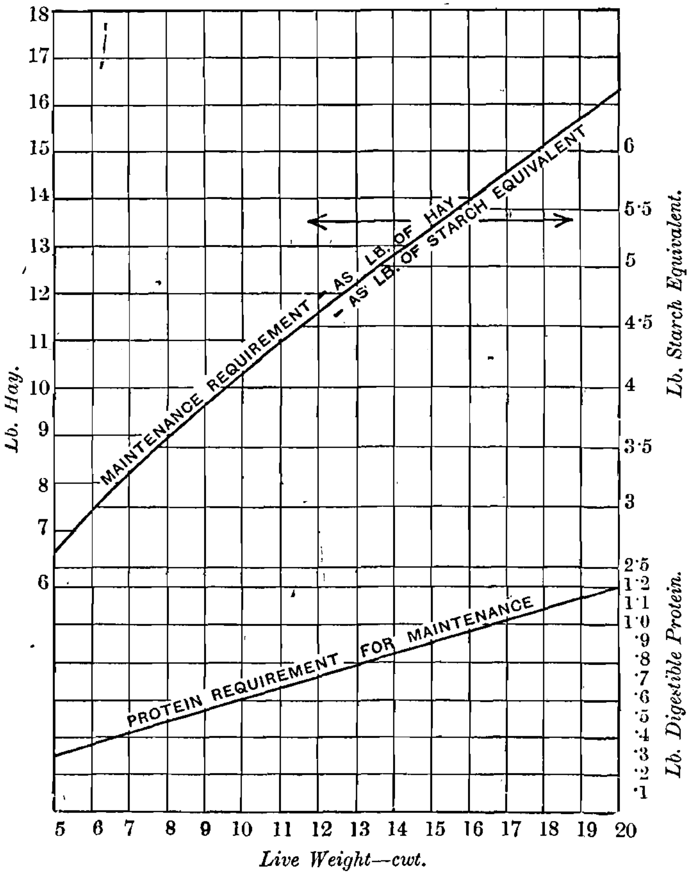


Diagram V.

CHAPTER XXVII.

PURCHASING FEEDING STUFFS.

Why Farmers Buy Feeding Stuffs.

In buying feeding stuffs it is important not to lose sight of the fact that it is impossible to form an exact estimate of their cheapness or dearness from a consideration of their price per ton or per quarter. Animals require definite amounts of protein, fat, and carbohydrate, and it is to provide an adequate supply of these substances that feeding stuffs are bought. Their cheapness or dearness, therefore, depends on the price at which they provide proteins, fats, and carbohydrates. It is here that the difficulty arises. If a feeding stuff contained only one of these constituents it would be easy to calculate its price. For instance, in the case of a feeding stuff containing 70 per cent. of carbohydrate, no protein and no fat, and costing £7 per ton, the price of the carbohydrate would obviously be £7 ÷ 70 or 2s. per 1 per cent. of a ton.

As a fact, however, practically all feeding stuffs contain all three ingredients, and in order to compare prices it is necessary to devise some method of reducing the three ingredients to a common measure so that they can be added together into one figure which will measure the total nutritive value.

Food Units.

Several methods have been used to achieve this end. Taking them in order, the first was known as the food unit method, and was worked out thus. Referring back to Chapter XX. it will be found that the amount of heat given out in the body of

an animal by 1 lb. of each of the three main constituents of feeding stuffs is:—

	Heat value per lb.
Protein	2,130 Calories
Fat	4,000 ,,
Carbohydrates	1,707 ,,

It is obvious that these figures provide a common basis for comparing the values of protein, fat, and carbohydrates. Taking the heat producing value of carbohydrates per lb. as 1, then the relative values of protein per lb. will be 2,130 ÷ 1,707 or 1·23, and of fat 4,000 ÷ 1,707 = 2·3. Applying these values to a feeding stuff, say linseed cake, it is possible to find the percentage of carbohydrate which will have the same heat producing value as the combined percentages of protein, fat, and carbohydrate shown by the analysis. Thus:—

	Linseed cake. Analysis per cent.		
Water	11·2	—	—
Protein	29·5	× 1·23	= 36·5
Fat	9·5	× 2·3	= 21·8
Carbohydrate ...	35·5	× 1	= 35·5
Fibre	9·1	—	—
Ash	5·2	—	—
			93·8

A linseed cake of average composition will therefore give out as much heat in the body of an animal as if it contained 93·8 per cent. of carbohydrate and no protein and fat.

But it must not be forgotten that when an animal eats a feeding stuff, although the carbohydrates and fat are either converted into fat or lost in the breath of the animal, the nitrogen of the protein and the ash are excreted in the dung and urine and serve to increase the value of the animal's manure. On this subject refer back to *Chemistry of Crop Production*, Chapter XIII. This being so, every ton of feeding stuff purchased will bring onto the farm a certain

manurial value which depends chiefly on the percentage of protein which it contains. A rough and ready way of allowing for this is to increase the protein factor from 1·23 to 2·3, when the carbohydrate equivalent of the feeding stuff is calculated thus:—(protein % + fat %) × 2·3 + carbohydrate % = carbohydrate equivalent. In the case of linseed cake:—(29·5 + 9·5) 2·3 + 35·5 = 39·0 × 2·3 + 35·5 = 89·7 + 35·5 = 125·2 = carbohydrate equivalent.

Linseed cake contains, therefore, the equivalent of 125·2 per cent. of carbohydrate. For convenience the unit adopted was one hundredth of a ton, this quantity of carbohydrate equivalent being called one food unit. On this basis linseed cake contains 125·2 food units, and if the price is £12 per ton, the price per food unit is £12 ÷ 125·2, or 240/- ÷ 125·2 = 1/11.

Similarly, if cotton cake containing 22 per cent. of protein, 5 per cent. of oil, and 25 per cent. of carbohydrates costs £7 per ton, the price per food unit is found thus:—

$$(22 + 5)\,2{\cdot}3 + 25 = 87{\cdot}1 \text{ food units.}$$
$$£7 \div 87{\cdot}1 = 140/\text{-} \div 87{\cdot}1 = 1/7.$$

Digestible Food Units.

This method was for a long period the recognised way of comparing the relative value of feeding stuffs. As knowledge was increased, however, it became evident that the method would be improved by taking into account the digestible instead of the total nutrients and calculating digestible food units. The procedure is exactly the same, except that the calculation is based not on the analysis but on the average percentage of digestible proteins, fat, carbohydrate, and fibre. Thus for linseed cake:—

Percentage digestible nutrients.

Protein ...	25·3 × 2·3 =	58·2
Fat	8·7 × 2·3 =	20·0
Carbohydrates	28·5 × 1·0 =	28·5
Fibre... ...	4·5 × 1·0 =	4·5
Digestible food units	=	111·2

At £12 per ton cost per digestible food unit $= \frac{240}{111{\cdot}2}/\text{-}$

= 2/2.

The digestible food unit method of comparing values was certainly an improvement on the older method, but it still possessed two defects. The digestible nutrients of all feeding stuffs are not of the same value : consequently any system of valuation based upon digestible nutrients must be lacking in accuracy. Secondly, the food unit method is a kind of hybrid between nutritive value and manurial value, and therefore although it was useful as a guide in purchasing it could not be applied to rationing.

Starch Equivalent or Net Energy.

It has now been replaced by an application of the starch equivalent or calorie idea. The best measure of the real nutritive value of a feeding stuff is its content of starch equivalent or net energy. But in buying a feeding stuff its manurial value should certainly be taken into account. The modern procedure is as follows: From the price of feeding stuff per ton subtract the manurial value per ton as given in Tables I. to IV., in *Rations for Live Stock* or elsewhere. This gives the net cost of the nutritive as distinct from the manurial constituents. Divide this by the starch equivalent per 100 lb., or by the number of therms of net energy per ton, and the quotient is the cost per unit of starch equivalent or per therm (1,000 Calories) of net energy.

Thus, in the case of linseed cake of average composition costing £12 per ton, the manurial value is 38/-. per ton. The nutritive constituents therefore cost £12 — 38/-. = £10 2s. per ton. The starch equivalent of 100 lb. of linseed cake is 74. The cost per unit of starch equivalent is therefore £10 2s. ÷ 74, or 2/8¾. Linseed cake contains per 100 lb. 79 therms (79,000 Calories), or per ton 79 × 2,240 ÷ 100 = 1,760 therms. The cost per therm of net energy is therefore £10 2s. ÷ 1,760, or 1·38d.

The unit of starch equivalent used above is one-hundreth of a ton or 22·4 lb. By dividing the cost per unit of starch equivalent by 22·4 the cost per lb. of starch equivalent can be found. Thus cost per unit of starch equivalent in linseed

cake as above, 2/8¾. Cost per lb. of stareh equivalent 2/8¾ ÷ 22·4 = 1·46d. For many purposes this is a more useful figure. For instance, in rationing animals the daily requirements were reckoned in lb. starch equivalent. The cost per lb. starch equivalent is therefore useful in assessing the cost of the daily ration.

Thus, the ration per gallon of milk being 2¼ lb. starch equivalent, if this can be bought at 1·46d. per lb., the cost of the ration will be 2¼ × 1·46d. or practically 3¼ per gallon. This of course is the cost over maintenance. If the maintenance ration is 6 lb. of starch equivalent, and the cow produces 4 gallons of milk, in producing which she consumes 4 × 2¼ = 9 lb. starch equivalent, her total consumption will be 15 lb. starch equivalent. This will cost 15 × 1·46d. or 21·9d., which is 21·9 ÷ 4 = 5½ per gallon.

The cost per unit and per lb. of starch equivalent of a number of common feeding stuffs at current prices are given each month in *The Journal of the Ministry of Agriculture* in "Notes on Feeding Stuffs." These notes provide a very useful guide as to the relative cost of starch equivalent in the common feeding stuffs.

Cost, however, is by no means the only criterion of value.

Price not only Criterion of Value.

In buying feeding stuffs their suitability for the purpose for which they are required must also be taken into account, and this suitability may be looked at from two points of view: composition and what may be called for want of a better word—wholesomeness.

Nutritive Ratio.

In order to decide if a feeding stuff is suitable from the point of view of composition it is necessary to know first the composition of the deficit which it is required to make good. In choosing a feeding stuff to make good the deficit in protein of a ration of home grown roots and straw, evidently a feeding stuff rich in protein is required. Richness in protein is, however, not always measured by the percentage of protein in the

feeding stuff. Skim milk, for instance, is rich in protein though it contains only a low percentage. Richness in protein should be measured relatively to the percentage of other ingredients. The usual way to express this relative richness in protein is by means of what is known as the albuminoid or nutritive ratio, which is the ratio of the protein to the non-protein constituents. In calculating this ratio it must be remembered that weight for weight fat gives out 2·3 times as much heat as carbohydrates. The formula for calculating the nutritive ratio therefore is:—

$$\frac{\text{digestible fat} \times 2{\cdot}3 + \text{digestible carbohydrates and fibre}}{\text{digestible protein}}.$$

Thus the nutritive ratio of linseed cake of normal composition is:—

$$\frac{8{\cdot}7 \times 2{\cdot}3 + 28{\cdot}5 + 4{\cdot}5}{25{\cdot}3} = \frac{53{\cdot}0}{25{\cdot}3} = 2{\cdot}1.$$

This means that for every lb. of digestible protein in linseed cake there are 2·1 lb. of digestible nonprotein reckoned as carbohydrate. The ratio of protein to non-protein is 1 : 2·1. This is what is called a narrow ratio, and implies that the linseed cake is comparatively rich in protein.

How to Use Nutritive Ratios.

Approximate nutritive ratios are given for many feeding stuffs in Tables I. to IV. and in *Rations for Live Stock*. They are quite useful in showing at a glance the relative richness of feeding stuffs in protein. It has been customary for many years to use nutritive ratios in the computation of rations, and this custom has given rise to many very serious mistakes. A few instances will suffice to show the pitfalls which beset the amateur, or even in some cases the expert, who tries to compute rations by this method. Thus, to calculate the proportions in which barley and fish meal should be mixed in order to provide a ration for pigs, with a nutritive ratio of 1 : 7, the following method has been recommended. The nutritive

ratio of barley is 1 : 10·4, that of fish meal 1 : ·193. The required ratio is 1 : 7.

Barley nutritive ratio			
1 : 10·4 :	5 parts barley	5 : 52·0	
Fish meal nutritive ratio			
1 : ·193 :	2 parts fish meal	2 : ·386	
	7 parts mixture	7 : 52·386	
Nutritive ratio of mixture		1 : 7·3	

This calculation is entirely wrong, and the error is so large as to be serious. The correct ratio of the above mixture is found thus:—

100 lb. barley contain 6·5 lb. digestible protein, 1·2 lb. digestible fat, 62·2 lb. digestible carbohydrates, and 2·5 lb. digestible fibre. 500 lb. will, therefore, contain 32·5 lb. of digestible protein, 6·0 lb. digestible fat, 311·0 lb. digestible carbohydrates, and 12·5 lb. digestible fibre.

100 lb. of fish meal contain 50 lb. of digestible protein, 4·2 lb. of digestible fat, no carbohydrate, and no fibre. 200 lb. will, therefore, contain 100 lb. of digestible protein and 8·4 lb. digestible fat. Thus:—

Digestible	Protein,	Fat,	Carbohydrate,	Fibre.
500 lb. barley ...	32·5	6·0	311·0	12 5
200 lb. fish meal...	100·0	8·4	—	—
700 lb. mixture ...	132·5	14·4	311·0	12·5

The correct ratio is therefore:—

$$\frac{14{\cdot}4 \times 2{\cdot}3 + 311{\cdot}0 + 12{\cdot}5}{132{\cdot}5} = \frac{356{\cdot}6}{132{\cdot}5} = \mathbf{2{\cdot}7.}$$

The ratio calculated by the so-called short method is, therefore, nearly three times wider than the correct ratio, and anyone feeding a mixture computed by this method would be giving his animals nearly three times the correct proportion of protein.

How to Make a Mixture of any Desired Nutritive Ratio.

There are two methods by which the correct proportions can be worked out, one purely arithmetical but tedious, the other a very simple algebraical method as follows:—Barley contains 6·5 per cent. of digestible protein, and $1·2 \times 2·3 + 62·2 + 2·5 = 67·5$ per cent. of nonprotein reckoned as carbohydrate. Fish meal contains 50 per cent. of digestible protein, and $4·2 \times 2·3 = 9·7$ per cent. of non-protein reckoned as carbohydrate. Let x = the number of lb. of barley to be mixed with 1 lb. of fish meal in order that the mixture may have a nutritive ratio of 1 : 7; then the nutritive ratio of the mixture will be $\frac{67·5x + 9·7}{6·5x + 50}$, and this must be = 7. Therefore :—

$$\frac{67·5x + 9·7}{6·5x + 50} = \frac{7}{1}, \quad \therefore 67·5x + 9·7 = (6·5x + 50) \times 7$$

$$\therefore 67·5x + 9·7 = 45·5x + 350,$$

$$\therefore 22x = 340·3,$$

$$\therefore x = 15·5.$$

The correct mixture is, therefore, 15·5 parts of barley to 1 part of fish meal, which will give a nutritive ratio of 1 : 7, thus—

	Digestible Protein,	Fat,	Carbohydrate,	Fibre.
1 lb. barley ...	·065	·012	·622	·025
15·5 lb. barley	1·0075	·186	9·641	·3875
1 lb. fish meal	·5	·042	—	—
16·5 lb. mixture	1·5075	·228	9·641	·3875

The nutritive ratio of the mixture will be :—

$$\frac{·228 \times 2·3 + 9·641 + ·3875}{1·5075} = \frac{10·5529}{1·5075} = 7.$$

The calculation of the nutritive ratio of a mixture, or the computation of a mixture which shall have a given nutritive

ratio is not a very simple matter. It can only be done correctly by taking into account the actual quantities of protein, etc., in the various ingredients. Attempts at short cuts are almost sure to cause serious errors.

Alternative Method.

Fortunately, such calculations are not necessary. It is easier and more certain to compute the ration in terms of starch equivalent or net energy, and afterwards to check its protein content and adjust the ration if necessary. This is the method adopted in the chapters on rationing. The idea of nutritive ratio is, however, useful in so far as it assists in defining the relative richness of a feeding stuff in protein. To use it in computing rations is very liable to cause serious mistakes.

Some General Characteristics.

Richness in protein is, however, not the only point to be considered in regard to suitability of composition. An animal can only eat a definite *amount of bulk per day. The best measure of* bulk is the proportion of dry matter. The weight of dry matter which the capacity of the digestive organs of various animals allow them to consume is defined by the curves connecting live weight and food consumption given in Diagrams II. to V.

From these curves it is possible to read off the amount of dry matter which an animal of any given live weight will consume per day. This sets a limit to the bulk of the ration. The amount and character of the home-grown contribution to this is next decided, and its composition worked out in terms of dry matter, starch equivalent, and digestible protein. It will usually be found that the home-grown contribution provides plenty of bulk but is deficient in protein. The supplement to be purchased must, therefore, be not only rich in protein, but also concentrated, that is to say, low in water and fibre. An additional reason for this is that it would not be economical to pay costs of transport on water and fibre which are produced in plenty on the farm in the form of roots and other succulents, and in hay and straw.

Wholesomeness. Turning to the other aspect of suitability, namely, wholesomeness, information on this subject is better acquired by practical experience than from books. To make the best of feeding stuffs from this point of view is rather an art which comes from observation and experience than a science based on experiment and reasoning. There is, however, a mass of recorded experience on the subject which the live stock owner will find useful, and perhaps this is more readily available in Henry and Morrison's *Feeds and Feeding* (Lakeside Press, Chicago), than elsewhere. This book also contains comprehensive tables of analyses, digestibilities, and net energy values of feeding stuffs, feeding standards, maintenance rations, etc. In fact, it is an excellent reference book on all matters concerning the feeding of animals.

Summarising the above, the procedure in purchasing feeding stuffs should be:—

Procedure before Purchasing. 1. Decide the ration you will supply to your animals (see Chapters XXIII.-XXVI.) in terms of dry matter, digestible protein, and starch equivalent or net energy.

2. Work out the contribution which your home-grown feeding stuffs can make towards this, also in terms of dry matter, digestible protein, and starch equivalent or net energy.

3. From the difference between 2 and 3 estimate the composition of the supplementary feeding stuff which you must buy to make good the deficiencies of your home-grown ration.

4. From the tables of composition in *Rations for Live Stock*, or elsewhere, make a list of feeding stuffs, or preferably mixtures of feeding stuffs, which have the requisite composition.

5. From your own experience select from this list the feeding stuffs which on the ground of wholesomeness, palatability, and other characteristics are most suitable for the special purpose which you have in view.

6. Get quotations for these, and work out the cost per lb. of starch equivalent in each case by the method shown above. This will show you which of the feeding stuffs in your select list will give you what you want at the lowest cost.

7. In buying insist on a definite guarantee of genuineness, purity, and composition.

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